Aluminum Casting Alloys

AND ALLOYS FOR OTHER PURPOSES

ALCOA

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1943

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ALUMINUM COMPANY OF AMERICA
Pittsburgh, Pennsylvania

Some of the alloys included in this booklet, methods of casting, heat treating and finishing, or the products of one or more of these operations, are covered by United States Patents.

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Choice of Materials

WIDER USE of aluminum alloys in the casting industry in the past few years is the natural result of a more general appreciation of their properties. The automobile and aircraft industries have been large users of aluminum castings, but today the aluminum foundry serves every major industry. Castings made from Alcoa aluminum alloys find important uses in ornamental and architectural work, in household appliances, in industrial machines, and in such vehicles as railway passenger cars, streetcars, buses, steamships and small pleasure boats.

Weight saving, particularly desirable in moving parts and assemblies, is an important advantage of aluminum alloy castings. Other properties include excellent resistance to corrosion, ease of applying surface finishes, desirable combinations of mechanical properties and high thermal and electrical conductivities. These qualities are usually the ones leading to the choice of aluminum alloy castings.

A comparison of the costs of aluminum alloys and other materials should be based, of course, on the price per casting, a comparison which takes into account the lighter weight of aluminum alloy parts. On a volume basis, aluminum alloys usually cost less than other commonly used non-ferrous sand-casting alloys.

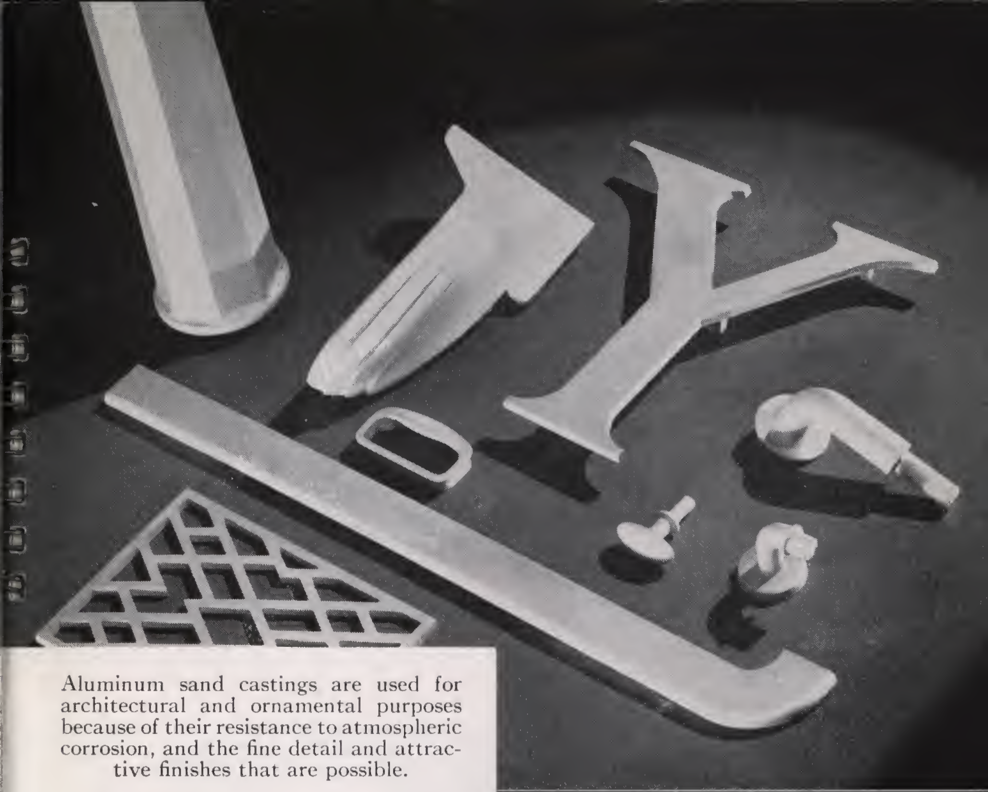
Some castings may require somewhat thicker sections in aluminum alloy than in another metal because of a difference in mechanical properties. Frequently, however, the section is determined by foundry considerations rather than

mechanical requirements, and the ability to cast aluminum alloys in relatively thin sections is an added advantage.

Savings from the use of aluminum alloys are by no means confined to cases where they show lower metal costs. Greater ease of machining and finishing aluminum may by itself result in a lower cost of the completed product, even in comparison with cast iron. Aluminum alloy castings are easily polished to give a pleasing durable finish, and save the expense of a plated coating required by some metals. Economy in packing and shipping may also merit consideration since aluminum alloys weigh but one-third as much as other common casting alloys.

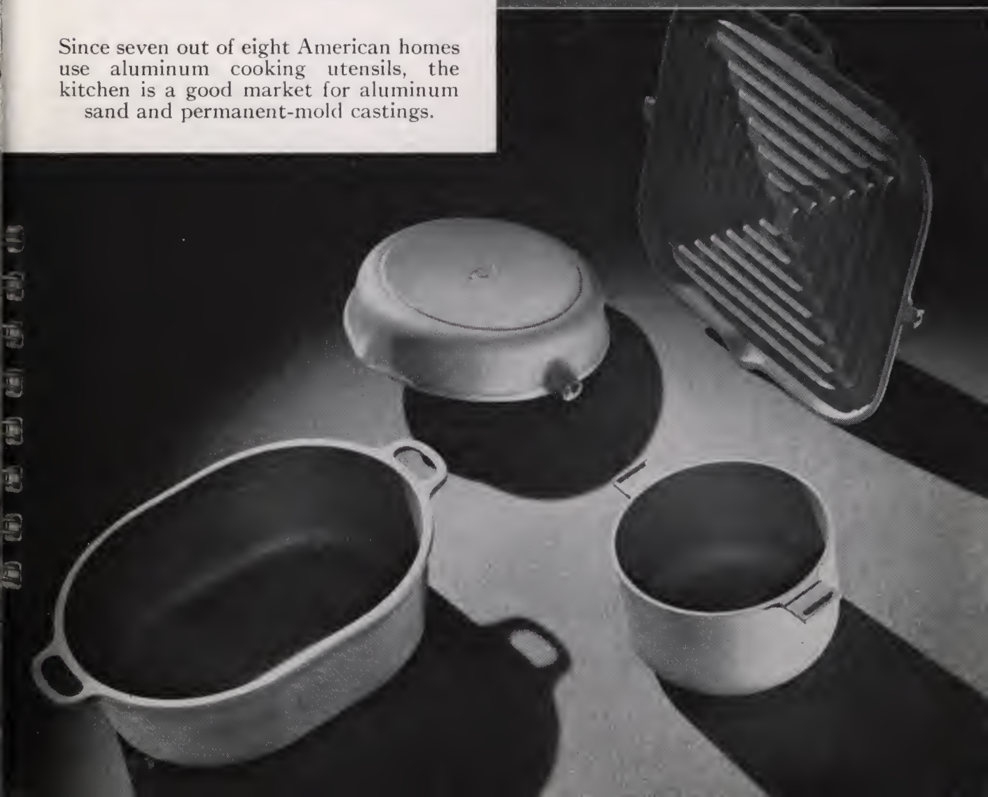
Superior performance and lower cost of operation constitute the major advantages afforded in many applications by the use of aluminum alloy castings. For example, a smaller amount of power is required to operate a lighter moving part or assembly. Stresses caused by vibration and by inertia are lessened by decreasing the weight of moving or reciprocating parts. Reduced weight generally results in longer life, smoother operation and lower repair and maintenance charges. These advantages have been largely responsible for the extensive use of aluminum alloys in the transportation industry.

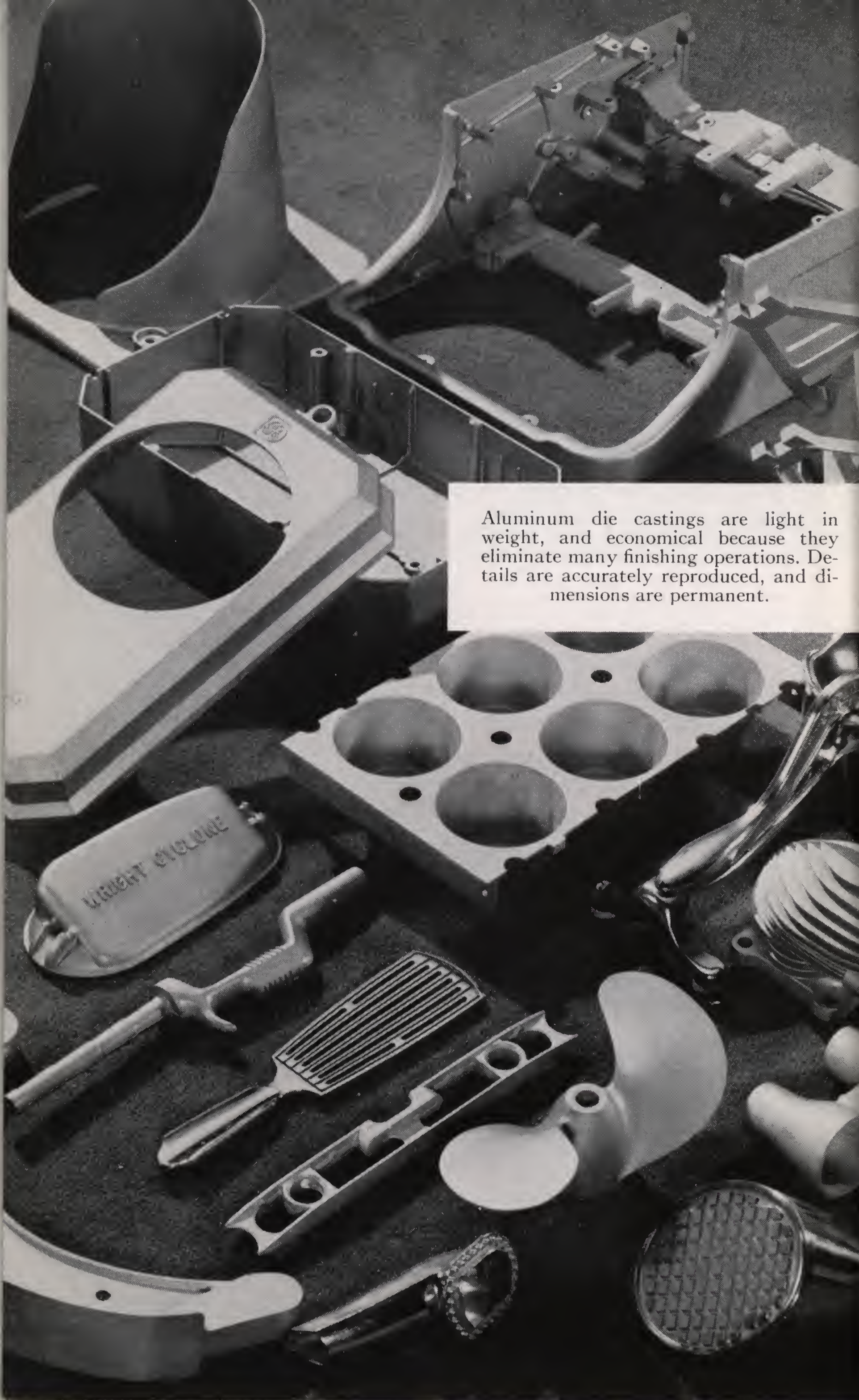
The higher scrap or inventory value of non-ferrous alloys as compared with iron and steel is also an item entering into cost comparisons. Aluminum alloy parts, and turnings and borings from these parts, command a high scrap price.



Aluminum sand castings are used for architectural and ornamental purposes because of their resistance to atmospheric corrosion, and the fine detail and attractive finishes that are possible.

Since seven out of eight American homes use aluminum cooking utensils, the kitchen is a good market for aluminum sand and permanent-mold castings.





Aluminum die castings are light in weight, and economical because they eliminate many finishing operations. Details are accurately reproduced, and dimensions are permanent.

Aluminum Ingot Products

ALCOA aluminum products for remelting are classed as casting alloys, rich alloys, aluminum and alloys of aluminum for additions to steel, and aluminum ingot and pig of various purities. Casting alloys of aluminum include alloys for use in sand, permanent mold and die casting, as well as for use with special molding materials and molding processes. Rich alloys, sometimes known as hardeners, comprise those aluminum alloys rich in specified elements. Such alloys are particularly useful in the making of casting alloys of aluminum and other metals. As the name implies, aluminum and alloys of aluminum for additions to steel include the various forms and compositions of material used for deoxidizing steel and for refining the grain.

This booklet provides information about the Alcoa ingot and pig products included in these classifications and which are regularly manufactured. Other products of special composition may be made on request. Further information regarding these products may be obtained from any of the sales offices listed on page 94.

CASTING ALLOYS OF ALUMINUM

Casting alloys may be of two types: the common alloys whose properties result solely from alloying additions, and the heat-treatable alloys with which heat-treatment processes are used to effect further improvement in properties. Which of these types of alloys should be used for any

specific application will depend on the mechanical properties required. Although the common alloys will adequately meet many casting requirements, there are numerous uses in which the higher properties of such heat-treatable alloys as Alcoa 195, 220, 355 and 356 may be required.

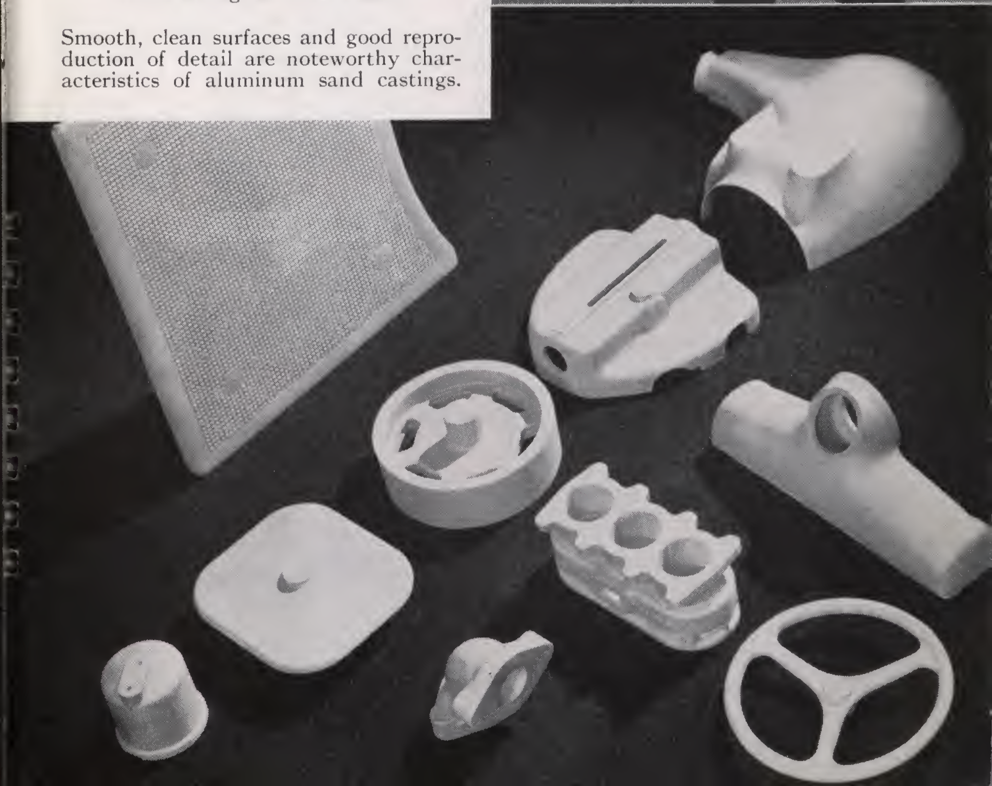
Aluminum casting alloys are, as the term indicates, metals containing a large percentage of aluminum and small amounts of other metals. Pure aluminum is used to a very limited extent for the production of castings because of its undesirable casting characteristics and low strength. The alloying of small percentages of certain other metals with aluminum not only improves the casting characteristics, but also increases the tensile strength, the yield strength and the hardness.

The elements commonly used in the production of aluminum casting alloys are copper, silicon, zinc, magnesium, manganese, nickel, chromium, titanium and iron, with tin being added occasionally to improve machining or polishing characteristics. Iron may be added intentionally in certain alloys to provide particular casting qualities, while in others the iron content is held as low as possible in order to maintain the desired mechanical properties. A high percentage of the total tonnage of commercial aluminum alloy castings produced at present in this country contains as alloy additions only copper or silicon, or a combination of these two metals, or copper and zinc, with controlled iron contents. The use of magnesium as a major alloying element in aluminum casting alloys is increasing, alloys containing about 4 per cent magnesium having a high resistance to corrosion and a pleasing appearance. Magnesium in smaller amounts is also an important addition to certain common and heat-treatable alloys, while the magnesium contents are rigidly restricted to negligible quantities in other alloys because of its undesirable effect on ductility.

Foundries find it advantageous to purchase Alcoa alloys in ingot form instead of making their own aluminum alloys,

Since they are pressure tight and resist corrosion, aluminum sand castings are widely used for pipe fittings. Permanent-mold fittings are also made.

Smooth, clean surfaces and good reproduction of detail are noteworthy characteristics of aluminum sand castings.



Permanent and semi-permanent mold castings are characterized by soundness and smooth surfaces. They have close dimensional tolerances, permitting thin sections and reducing finishing costs.

because Alcoa ingot is produced under properly controlled conditions. Alcoa casting alloys are produced in heats of 500 to 20,000 pounds, and each heat is carefully sampled and analyzed to check the chemical composition. These alloys are melted carefully under constant pyrometric control, and every precaution is taken to produce a product which will give uniformly satisfactory results in the foundry. This control is especially necessary in the case of the heat-treatable alloys, as the maintenance of close chemical composition and other characteristics is essential to satisfactory application of the heat-treating process.

The common Alcoa aluminum alloys regularly manufactured for the castings trade are described on pages 63 to 74, and their compositions, properties and conforming specifications are given in the Appendix. Similar data on the heat-treatable alloys will be found in the booklet "Alcoa Aluminum and Its Alloys," which can be obtained from any of the sales offices listed on page 94. Since the heat treatment of castings of these latter alloys requires special equipment and is subject to license under patents, inquiries with respect to the heat-treatment process should also be addressed to the sales offices.

The properties of castings produced from our alloys cannot be guaranteed by us, since the mechanical properties of an alloy casting depend so much on remelting of the alloy and foundry technique, both of which are beyond our control. Test bars poured in our own foundries from remelted heats of each lot of ingot produced must meet our minimum specified tensile properties before the lot is released for shipment. It should therefore be possible for foundries using Alcoa ingot to meet similar specifications, providing good commercial care is exercised in handling the metal and if test bars are made in accordance with established gating and pouring practices.

RICH ALLOYS OF ALUMINUM

For foundries which prefer to make their own alloys, standard aluminum-rich alloys, or hardeners, are supplied. These hardeners facilitate the making of alloys, particularly in small heats as well as when the elements that are to be added have high melting points and are, as a result, difficult to diffuse uniformly in the molten base metal.

Rich alloys of aluminum containing copper, silicon, manganese, nickel, zinc, titanium or iron—either singly or in combinations—are useful in making up aluminum alloys for either sand, permanent-mold or die castings. Production of certain zinc-base alloys for die castings is also made easier by the use of rich alloys. The problem of adding iron to aluminum bronze is solved by using an alloy containing 90 per cent aluminum with 10 per cent iron, which insures uniform iron distribution.

The addition of a small amount of titanium to certain aluminum alloys improves the metal structure, casting characteristics and mechanical properties. Such an addition may be made either during alloying of the metal or during remelting, just before pouring. In either case, care must be taken to insure a uniform diffusion of titanium throughout the metal, and the use of a titanium-rich aluminum alloy is recommended.

A few commonly used rich alloys of Alcoa aluminum are listed in Tables II-A and II-B of the Appendix. Other compositions are produced on request.

ALUMINUM AND ITS ALLOYS FOR STEEL ADDITIONS

The importance of aluminum in steel manufacture has long been recognized not only as a deoxidizing agent but also as an alloying element and grain refining agent. Of the various elements used as deoxidizers, aluminum, on a

cost basis, is the most effective and affords the most nearly complete reduction of iron oxide.

During the past decade a fund of accurate information on the physical chemistry of steelmaking has come from steel plants and the laboratories of universities and government bureaus. Any idea that aluminum oxide inclusions cause a steel that is dirty and difficult to machine has been disproved by tests which show that alumina particles of suitable size and distribution may be very beneficial. As a result, the importance of grain-size control of commercial steels by means of aluminum has now become well recognized. Additions ranging from a few ounces to 4 pounds per ton of steel make possible the production of steels with a wide range of grain sizes and mechanical properties. The aluminum-killed steels are of the fine-grained shallow-hardening type and are characterized by high impact strength and a markedly reduced tendency to distort during the quenching operation after heat treatment.

Aluminum may be added in several forms, depending on the preference of the user. Metallurgical aluminum, containing a minimum of 94 per cent of the element, is used in ingot, granulated, grained and coiled-rod forms. Material of higher purity, containing a minimum of 99 per cent aluminum, is normally supplied in ingot, granulated or grained forms. Aluminum-iron and aluminum-manganese-silicon rich alloys for ladle or furnace additions are usually supplied in lump form for ease of handling.

In the past, aluminum has been extensively used in the final stage of deoxidation of killed steel by additions in the ingot molds. About 0.25 pound of aluminum per ton of steel is generally used for this purpose. However, in recent years the tendency has been to introduce aluminum in the ladle, and in some cases it has been combined with silicon and manganese for use as a preliminary deoxidizer in open-hearth or electric furnaces. At present, aluminum additions for deoxidation range from about 0.5 pound to 4 pounds

per ton of killed steel, the amount depending upon the grade of steel, the slag, other deoxidizers used and the grain size desired.

Aluminum is used in rimming and semi-killed steels to reduce the active ferrous oxide and to control the evolution of gases during the rimming action in the ingot molds. It is added to rimming steels in amounts up to 0.4 pound per ton of steel in the ladle and 0.2 pound in the mold.

Standard Alcoa aluminum alloys manufactured for the steel trade are listed in Table III of the Appendix. Other compositions are manufactured on request.

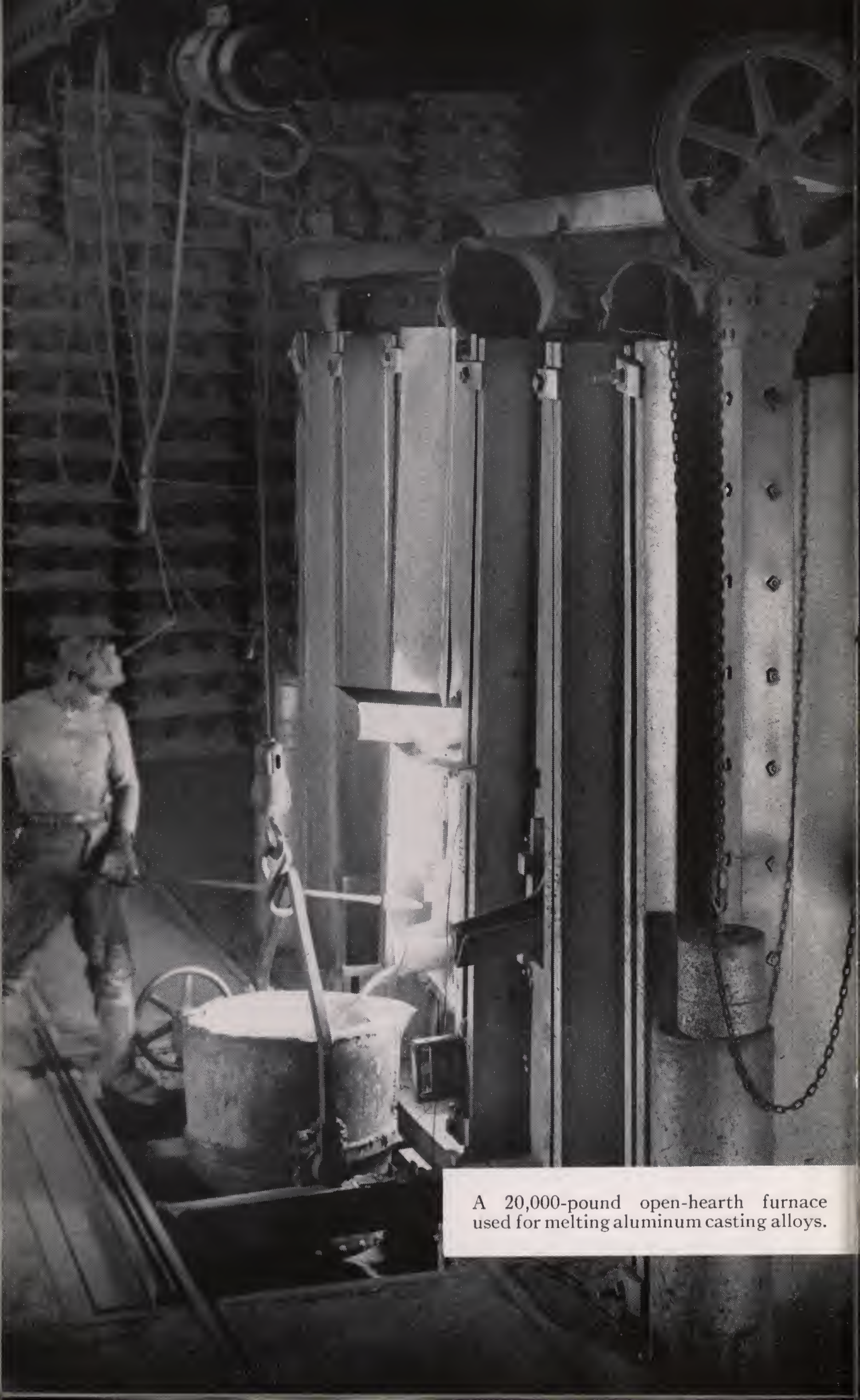
General Foundry Principles

THE MAKING of castings of any of the commercial metals is an art, and some measure of skill in this field must be acquired through experience. When the casting art used but a few metals cast in sand molds, as was the case not so many years ago, acquiring such experience was not difficult. Today, however, with a great variety of casting alloys and additional casting methods, the making of castings has become more specialized.

A knowledge of the foundry characteristics of aluminum alloys is necessary for the production of high-quality castings. Having this information, it is possible to establish practices that will be effective in controlling the many foundry variables. While the following comments apply mainly to the sand-casting process, many of the practices are also suitable for the permanent-mold and die-casting processes as well.

MELTING

One of the most readily controlled variables, and at the same time one of the most frequently overlooked, is the melting practice. Between the charging of the metal into the furnace and final delivery of molten metal to the mold, there are numerous places where failure to exercise adequate control will be reflected in a reduction of the final casting quality. Foundries producing castings of uniformly good quality are those which establish a careful melting



A 20,000-pound open-hearth furnace used for melting aluminum casting alloys.

procedure and adhere strictly to that procedure. Of course the proper pouring temperature must be established for each individual part.

Aluminum alloys have two characteristics which become important factors during melting. The first is a readiness of the molten metal to absorb certain gases, particularly hydrogen. Water vapor, hydrocarbon gases and other hydrogen-containing compounds usually are the sources of this gas. These materials, under certain conditions, react with the molten metal and liberate hydrogen. Since this reaction increases rapidly with temperature, temperatures in excess of 1300° F. for metal melted in direct-flame furnaces and 1500° F. for metal melted in indirect-flame furnaces are to be avoided.

The second important characteristic of aluminum alloys is the readiness with which they combine with oxygen to form oxides. In the case of the solid metal, this is a material advantage since these oxide coatings account for the excellent resistance of aluminum to corrosion. However, oxide films do introduce certain melting problems. Again, the amount of oxide formed during melting increases with the temperature as well as with agitation. With most of the heavier metals this is not so important a consideration as with aluminum, since the specific gravity of their oxides differs sufficiently from that of the metal to make possible a rapid separation. The specific gravities of aluminum alloys, however, are sufficiently close to that of aluminum oxide to make the separation more difficult.

Furnace Equipment—The first important consideration in melting aluminum alloys is the selection of suitable furnace equipment. This selection depends, to a large extent, on the requirements of each foundry, but it also should be made with the characteristics of the metal in mind. Furnaces of widely differing designs are available, and the choice should be made not only on the basis of

Metal for small castings is here being ladled from 300-pound stationary iron-pot furnaces provided with accurate temperature control.

capacity and melting efficiency, but also from the standpoint of design which will result in minimum gas absorption and oxidation. It may be found necessary to sacrifice something in connection with furnace capacity or melting efficiency to secure design features which will promote high metal quality. In the end, such a compromise generally will more than pay for itself through the improved quality of the final castings.

Furnaces used for melting aluminum alloys generally fall under two classifications: the direct-flame furnace, in which the flame or products of combustion come in direct contact with the metal; and the indirect-flame furnace, in which metal is melted without coming in direct contact with the heating medium.

Indirectly fired pot type furnaces are used most commonly in aluminum foundries. Such furnaces may be either of the stationary type, from which the metal is ladled by hand, or of the tilting type, which permits the metal to be poured into the ladles. Cast-iron pots are generally used with such furnaces, although nonmetallic pots of graphite or various vitreous and refractory materials offer certain advantages for some melting conditions. Pots of these latter materials are particularly useful for melting aluminum-silicon and aluminum-magnesium alloys, where a minimum of iron pickup must be maintained to preserve the mechanical properties and resistance to corrosion shown by these alloys when of the desired purity.

Open-hearth and barrel type furnaces are direct-flame furnaces. Although these provide the cheapest melting, and the open-hearth furnace is particularly suited to alloying large quantities of metal, they have certain disadvantages for average aluminum foundry use. Direct contact with products of combustion requires that such furnaces be operated at fairly low temperatures, that is, temperatures lower than normally required for foundry use, to minimize the risk of absorption of excessive gas by the metal.

Metal for larger castings is here being remelted in 400-pound iron-pot furnaces.

Pit type crucible furnaces, when used with aluminum alloys, should be fitted with a crucible cover or designed to keep the products of combustion away from the open top of the crucible.

Furnaces of either general type may be fired with gas, fuel oil, coke or electricity. Gas and fuel oil find most general use because of the convenience and economy which they offer. Coke, which is used to some extent for remelting for foundry use, is relatively economical, but is not as satisfactory in obtaining accurate temperature control.

Electricity has found relatively little use as a heating medium for aluminum melting furnaces, although theoretically it should offer certain advantages. Power cost probably has been the deciding factor against its use for the purpose. Of the various types of electric furnaces, the induction furnace appears to offer the best possibilities. This type of furnace is being used abroad to a limited extent with aluminum alloys and may find increasing favor in the foundry field.

Temperature Measurement—Without proper means of measuring metal temperatures, even the best furnaces may produce inferior metal. As mentioned previously, both the gas absorption and the oxidation tendencies of aluminum alloys increase with the temperature of the molten metal. In addition, high melting and holding temperatures have a harmful effect on the metal structure. Metal which has been overheated will show a coarser, more open grain structure than metal which has been melted properly, even though cooled to a low temperature before removal from the furnace. Holding the metal at even moderately high temperatures also tends to coarsen the grain structure. The higher the holding temperature, the shorter the time required to produce this result. It is therefore desirable that each furnace, even if not equipped with automatic temperature control, have at least suitable temperature-indi-

Pouring temperatures are checked and recorded at control stations conveniently located on the foundry floor.

cating equipment to insure the maximum metal quality.

In neither the solid nor liquid condition do aluminum alloys show their temperature by sharp color changes. It is not possible, therefore, to judge the temperature of the molten metal by its color, as in the case of certain other metals, so it becomes necessary to use suitable pyrometric equipment. The thermoelectric type, consisting of a thermocouple, suitable compensating leads, and a millivolt meter calibrated to record the temperature, is most commonly used. Closed or beaded-end thermocouples of chromel-alumel wires, protected by a cast-iron tube, are generally used for measuring temperatures in the melting furnaces. Open-end couples, made from No. 8 gauge asbestos-covered chromel-alumel wires, provide rapid and accurate means of determining temperatures in pouring ladles. Portable pyrometric equipment, capable of being moved from furnace to furnace, or stationary equipment with several thermocouples and a selector switch, is commercially available for foundry temperature control.

Melting Precautions—Chemical composition limits of aluminum alloys are maintained to provide certain characteristics, among which are the physical and casting properties. Altering the composition by contamination with foreign metallic elements picked up during melting and pouring may affect these characteristics adversely, and foundry difficulties may result. It is comparatively easy, especially in foundries using a variety of metals, to contaminate the aluminum alloys, either through a mixing of the foundry scrap or by melting or pouring in equipment used previously for other materials and not thoroughly cleaned. It is comparatively easy to establish a system to segregate the various metals and to insure a thorough cleaning of equipment between heats of different alloys. Such a system will aid materially in establishing a foundry metal supply with uniform characteristics.

The necessity for proper care of melting pots, pouring ladles or other equipment which may come in contact with molten metal should be emphasized. The effect of contamination of metal from dirty equipment is often serious. Pots themselves should be cleaned thoroughly by scraping the walls to remove any loosely adhering scale which ultimately might work off into the metal. Iron pots, as well as other iron equipment, should be kept thoroughly coated at all times as a protection against iron pickup. A coating of whiting or of Alorco Insulating Powder is used with good results in many foundries. Mixtures prepared by adding 7 pounds of either material per gallon of water are of suitable consistency for application by brushing. Some users prefer to add a small amount of sodium silicate to improve adhesion. After each cleaning, the coating should be renewed by heating the pot to a temperature slightly higher than the boiling point of water and brushing the mixture on its surface to form a continuous film of moderate thickness. A newly coated pot should be thoroughly preheated to be sure that all the moisture is driven off before metal is again charged into it.

Agitation of the molten metal, either in the melting furnace or while it is transported to the mold, increases oxide formation. Continual skimming of the metal increases the total oxide loss since each time the protective oxide coating is removed a new one forms. If the metal must be stirred, this should be done from the bottom upward, taking care to disturb the surface as little as possible. When transferring from furnace to ladle, or from ladle to ladle, the metal stream should be kept as short and with as few breaks as possible. It is preferable to skim only when ready to take the metal from the furnace and prior to pouring. By observing these simple practices, much of the difficulty attributable to oxides and dross can be eliminated.

The same practices that are beneficial in reducing oxidation also decrease gas absorption, but in addition, careful

temperature control is necessary to prevent gas pickup. Selection of material for the charge is also a factor not to be overlooked since the condition of the metal composing a furnace charge may influence the final quality. Sawings, borings and scrap castings are often coated with oil, grease or moisture. While all of these forms of metal can be used satisfactorily in making castings, it may not always be possible to use them directly in a furnace charge without some preliminary preparation, as the oxide coating or film of oil may produce sufficient gassing to cause unsoundness in the final castings. In some cases, preheating such material at a sufficiently high temperature to drive off the volatile matter will eliminate any trouble. In other cases it is preferable to melt the scrap material separately, pour it into ingot molds, and use the resulting ingot in subsequent furnace charges.

Fluxing—There are several fluxing treatments designed to help rid aluminum of excessive oxide and gas formed or absorbed during poor melting. However, it is better to minimize the need for fluxing by the use of a satisfactory melting and handling practice and careful selection of materials than to depend entirely on fluxing to produce a quality product. There are cases where fluxing is helpful, such as when melting aluminum-magnesium alloys, metal to which a considerable amount of foundry scrap has been added, or when reclaiming skimmings, turnings or other small scrap. These treatments will not correct the effect of a poor melting practice, or improper handling of the metal after it has been fluxed.

There are a number of materials commonly used, either alone or combined, as fluxes for aluminum alloys. These may properly be divided into two general classes: solid fluxes and gaseous fluxes. Solid fluxes may further be divided into two subgroups: (1) those which form a gas at the metal temperature and (2) those which merely be-

come liquid at that temperature. The liquid flux, which is largely employed as a protective covering for the molten metal, is required in the aluminum foundry only for a limited number of alloys. Aluminum chloride and zinc chloride are typical solid fluxes which form gas at the metal temperature. Such fluxes usually are introduced into the metal in solid form, and the resulting gas bubbling through the metal tends to remove oxides and dissolved gases. Nitrogen is a typical illustration of a gaseous flux and usually is introduced into the metal by means of a refractory or a coated iron tube. It operates in much the same fashion as the solid fluxes which become gaseous at the metal temperature.

The operation of fluxing must be carried out carefully if benefits are to be realized. In fact, unless proper control is exercised, more harm than good can be done the metal. When solid fluxes are used, they must be absolutely dry and introduced into the metal in a way that will avoid excessive agitation. Gaseous fluxes, likewise, must be free of water vapor and hydrogen. Generally, such gaseous fluxes are piped to the bottom of the melting pot and allowed to diffuse through the metal. The amount of flux required for maximum benefit is a matter to be determined by trial and depends considerably on the type of metal entering into a particular charge.

In fluxing with the more generally used solid fluxes, common practice is to heat the metal to a temperature of 1350° F. to 1400° F. before adding the flux. In melting finely divided scrap or alloys high in magnesium, it is preferable to sprinkle the flux over the solid metal immediately after it is charged into the pot in order to provide protection for the metal during melting. The required amount of flux can be determined by sprinkling a small quantity of flux on the molten metal, stirring it into the dross and continuing to stir in small additional amounts of flux until the dross becomes powdery or granular. The dry granular

dross produced by proper and complete fluxing can be removed readily with a perforated skimmer.

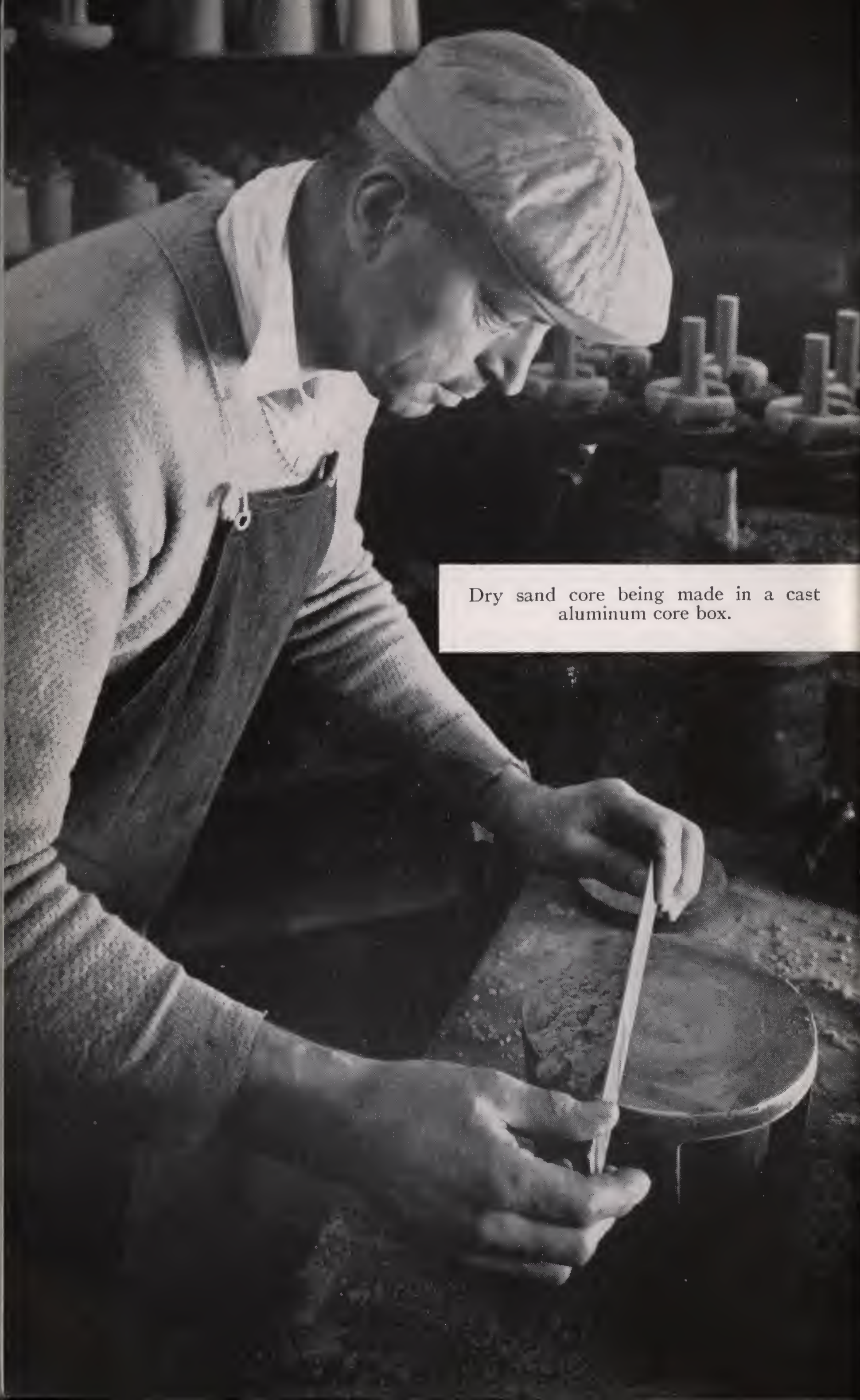
In addition to the solid fluxes previously mentioned, a mixture of 50 per cent sodium silico-fluoride with 50 per cent sodium chloride, and a mixture of 30 per cent potassium chloride and 70 per cent cryolite, have been found particularly suitable for fluxing heats consisting of skimmings, turnings and other small scrap.

MOLDING

The general methods of making molds used with other metals are quite suitable for aluminum alloys. Methods for handling and conditioning sand and practices of core making and molding are quite similar regardless of the metal used. However, the properties of aluminum alloys establish certain preferred molding practices which differ somewhat from those best suited to other metals.

The making of molds for casting aluminum alloys is not difficult when the characteristics of the metal are understood. Certain of these are natural properties of aluminum itself and are retained in all of the alloys, while others are the result of alloying additions and therefore peculiar to specific alloys. Some of the qualities of aluminum alloys simplify the problem of molding, while others make necessary the adoption of certain practices which differ from those used for other metals. A knowledge of these different characteristics and the practices they make necessary is essential to successful production of aluminum alloy castings.

One of the most significant characteristics of aluminum alloys which influences the molding practice is their light weight. Aluminum alloys weigh approximately one-third as much as brass, cast iron or steel. This characteristic is of distinct advantage in that it lowers mold pressures and permits lighter sand ramming. Mold equipment also can



Dry sand core being made in a cast aluminum core box.

be considerably lighter than that required for heavier metals, thus aiding handling. Small and medium-size casting molds usually can be poured without using weights, and it is often unnecessary even to place boxes or frames on such molds made in snap flasks.

On the other hand, the low density of aluminum makes it somewhat more difficult for its alloys to rid themselves of oxide or to drive off mold gases than is the case with the heavier metals. A molding practice which insures delivery of metal to the mold cavity with a minimum of oxide is therefore essential. Permeability of the mold also assumes greater significance in order to insure ready displacement of the air and water vapor by the metal as it enters the mold cavity. Proper control of these factors is not difficult if they are recognized during molding.

A second characteristic of aluminum alloys which demands consideration during molding is their hot shortness. At temperatures just below that at which the metal solidifies, the strength of aluminum alloys is quite low. Any abnormal resistance to contraction while a casting is passing through this temperature range may result in cracks.

The aluminum-silicon alloys are much less hot short than the aluminum-copper alloys, particularly those alloys containing less than 5 per cent copper. Proper choice of alloy, as well as care in molding to insure minimum resistance to contraction, is effective in overcoming casting cracks from this cause.

The third characteristic of aluminum which has an important bearing on the molding practice is its relatively high solidification shrinkage. Such shrinkage takes place rather quickly as the metal changes from the liquid to the solid state. Unless compensation for this reduction in metal volume is made, it may result in one or more of such common defects as draws, surface shrinkage, porosity or shrinkage cracks.

Producing a mold on a squeezer machine.

Again, the amount of solidification shrinkage, as well as the rate at which it occurs, varies with the particular alloy. Generally speaking, those alloys which solidify over the largest temperature range have the greatest shrinkage. For example, the aluminum-copper alloys require more feeding to eliminate the effects of such shrinkage than do the aluminum-silicon alloys.

Selection and Control of Sand—Aside from the effect on the surface appearance of the castings produced by the sand used for molding, proper selection and control of sand are of importance in relation to certain of the inherent foundry characteristics of the metal. There are a number of natural sands which meet the normal requirements.

For green sand molds, a clay-bonded sand essentially free from organic materials and falling within the A.F.A. classification 1G to 2G is quite satisfactory; the finer sand is best for small benchwork and the coarser sand for floor work. Sand of this type, tempered with 6 to 8 per cent water and rammed lightly, produces a very desirable surface on the castings and is open enough to permit ready escape of the mold gases. Facing of green sand molds is usually unnecessary if the proper molding sand is available and is conditioned and rammed properly.

Cores for aluminum alloy castings, in common with cores for castings of other materials, consist of mixtures of silica sands, and sometimes molding sands, together with a bonding material and water. The usual bonding materials are made chiefly from linseed and other oils, resin, dextrin, pitch, flour or combinations of these materials. The selection of the proper binder and the core mixture is dependent upon the use to which the core is put. The properties of cores may be regulated by varying the percentage as well as the kind of binder used. The properties and uses of a few typical core mixes are given in Table 1.

Cores should be as soft as is consistent with safe handling. Hot shortness of aluminum alloys requires the use of body

TABLE 1

Typical Core Sand Mixes for Aluminum Alloy Castings

Sands (Parts by Volume)	Binders (Parts by Volume)	Physical Properties: Approx. A.F.A. Permeability	Physical Properties: Approx. A.F.A. Compressive Strength, Lb./sq. in.	General Use
50—Bank sand 50—Washed silica sand*	1—Oil base 1—Dextrin base (dry bond)	50	200	Small to medium castings requiring very smooth surfaces.
100—Washed silica sand†	1—Oil base 1½—Dextrin base (green bond)	150	550	Jacket cores and cores with thin sections.
66—Sharp sand 34—Bank sand	1½—Oil base	85	350	General runs of small cores.
37—Bank sand 63—Burned core sand	2—Pitch base	40	100	Large body and housing cores.
25—Bank sand 63—Burned core sand 12—Molding sand	3—Dextrin base (dry bond)	25	325	Side cores in contact with metal on one side only.

SAND CHARACTERISTICS

Sand	Grain Shape	Grain Fineness
Bank sand	Subangular	90
Washed silica sand	Rounded	85
Washed silica sand	Rounded	65
Sharp sand	Angular	55
Molding sand	Subangular	270

*Grain fineness: 85.
†Grain fineness: 65.

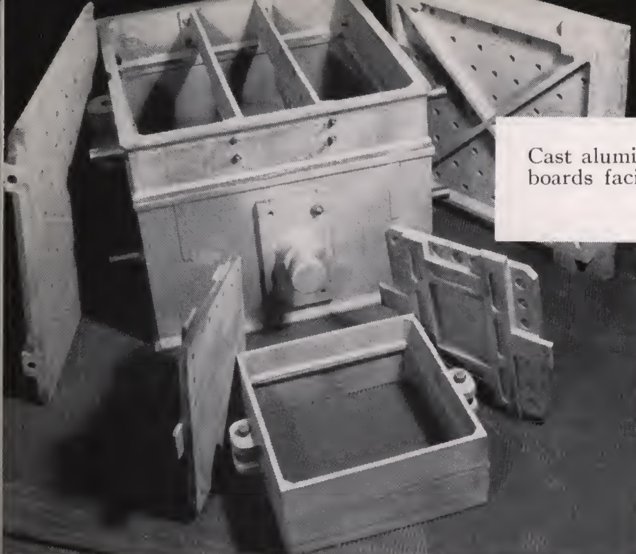
and housing cores that are soft enough to be crushed easily by the casting as it solidifies and contracts.

The light weight of aluminum alloys makes high core permeability necessary. Thorough venting of cores is important in preventing the occurrence of blows and porosity in castings. A core wash of either the talc or graphite type may be used to improve surface smoothness. Many foundrymen, however, prefer to use finer sands for making cores, which practice produces surfaces sufficiently smooth without the application of a core wash.

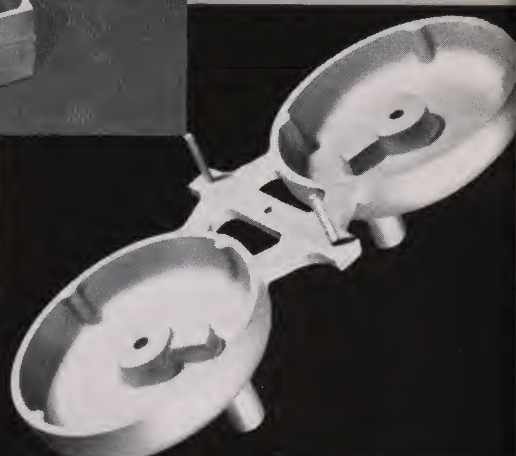
Gating and Risering—Gating of aluminum alloy castings is a part of the molding art, which, to a great extent, must be acquired by experience. Certain fundamental considerations and a knowledge of alloy characteristics serve as a guide, but the application of these to each particular casting is generally a matter of experience. Both the hot shortness and high shrinkage of aluminum alloy castings can be offset materially by the proper application of suitable gating practices.

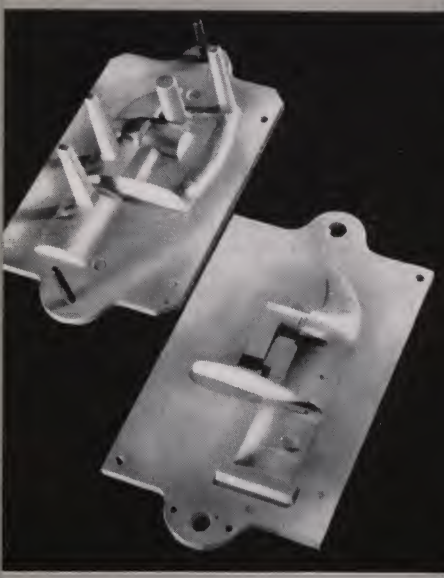
As a general rule, castings should be gated and fed in such a way as to provide a sequence of solidification which insures an adequate supply of molten metal to feed each section as it solidifies. The solidification should start at points furthest removed from the gated area and proceed progressively to the risers which provide liquid metal to take care of the shrinkage. To control this solidification sequence, it is frequently necessary to use chills embedded in the mold to hasten the solidification of the heavier sections. Chills for this purpose may be of aluminum, copper or cast iron and of such a size as required by the dimensions of the casting section.

Multiple gating is recommended for aluminum; that is, the metal should enter the mold cavity at a number of points instead of one or a few as in the case of certain other metals. Such multiple gates permit a lower pouring tem-



Cast aluminum alloy flasks and bottom boards facilitate handling of large and small molds.





Gated metal pattern (*above*), cope and drag equipment (*left*), and metal match plate (*below*) used in the production of aluminum alloy castings. The patterns themselves are aluminum castings.

perature, hence a lower temperature gradient and a better sequence of solidification.

Gates should be designed and placed on the pattern so as to insure metal entering the mold with a minimum of agitation, thereby reducing dross formation. Maintaining a smaller total cross-sectional area in the sprues than in the gates, and a larger cross-sectional area in the runners than in either the sprues or gates, aids in fulfilling this requirement. Use of rectangular sprues, pouring basins and skim gates is also effective in reducing metal agitation, particularly when using alloys which oxidize readily.

Risers, in addition to acting as reservoirs of liquid metal to feed the casting as it solidifies, also act as exits for mold gases and oxides, as pressure heads, and as means of reducing the temperature gradient within the casting. In order to make full use of these riser characteristics, a careful study should be made of each pattern to determine where the risers should be placed, how many should be used and their size.

In many cases, risers cut into the side of a casting, rather than on top, are more desirable. In such instances the gates should be cut into the risers. This practice will insure hot metal in the riser, provide additional skimming of the metal as it enters the mold and prevent the shrinkage sometimes found where the gate enters the casting.

The placing of gates and risers also may be influenced by cleaning considerations and flask equipment. Gates and risers are removed most readily from surfaces which are in relief, and, unless the casting soundness is impaired, should be placed on such surfaces. Also flask bars should be located so that they are not too close to risers. Proximity to these bars or other rigid flask parts may restrict the normal contraction of the casting and result in cracks.

Risers with a rectangular cross section, placed so their long axis is parallel to the long axis of the casting, are helpful in such cases. In special cases, it may be necessary

to place wood or metal wedges in the cope close to risers and to draw them out as soon as possible after pouring to help relieve the stresses that may be developed by undue resistance of the sand.

The necessity for minimizing metal agitation during the melting and handling of the metal has been discussed. Similar precautions should be exercised during the actual pouring of the casting. The metal should enter the sprue without splashing or violent agitation, and the stream should not be broken at any time during the pouring operation. The ladle should be held as close to the sprue as possible, as too great a pouring height often results in dross and trapped air in the final casting.

Summary—Dross inclusions, shrinkage, porosity and cracks are the principal defects to be avoided in the production of castings, not only in aluminum alloys, but in other metals as well. By the use of proper molding and metal handling practices, these defects can be eliminated or at least so minimized as to have no practical effect on the performance of the casting. Some of the more common defects are listed in the following summary, together with brief comments on their causes and methods of correction.

(*1*) *Shrinkage Cavities:* The presence of shrinkage cavities indicates a lack of feeding or failure to produce a suitable solidification sequence. This shrinkage usually can be eliminated by the use of adequate risers, by a suitable combination of risers and chills or by a change in gating so as to provide cooler metal in the sections in which the shrinkage occurred.

(*2*) *Surface Shrinkage:* Shrinkage which is confined near the surface, particularly that appearing as small "worm" channels, generally indicates a high pouring temperature. Revising the gating to permit pouring at a lower temperature, or to provide cooler metal in the questionable section, generally will overcome this condition. A similar

condition may also be the result of hard ramming, excessive moisture or the presence of volatile materials in the sand. Thin castings often show surface shrinkage near the gates which can be eliminated by a small riser on the runner close to the casting.

(3) *Dross and Blowholes:* Unsoundness due to dross and blowholes usually is caused by too much agitation of the metal and failure to exercise care in skimming and pouring. The use of scrap that has not been cleaned carefully prior to melting may cause such unsoundness. Careful observance of gating and pouring practices and the use of skim gates are effective in minimizing such defects.

(4) *Pinhole Porosity:* Porosity in the form of small, round, uniformly distributed cavities is sometimes revealed on machined surfaces of castings, especially in thick sections. In most cases this is probably the result of gas absorbed by the metal during melting and handling or from the mold. Better melting conditions, lower temperatures and care in the selection of the materials making up the metal charge will aid in reducing pinhole porosity. In addition, chilling and feeding are very effective. Lighter ramming of the mold to provide better permeability and control of moisture content are important considerations.

(5) *Cracks:* Cracks are usually the result of excessive resistance to the normal contraction of the casting during solidification and cooling. Consequently, elimination of the sources of this resistance is essential. Strengthening the sections where such cracks occur by means of ribs, fillets or fins is often desirable. Castings may be also cracked by careless knockout practice or by removing them from the mold before they are sufficiently cooled. Localized shrinkage, which results in a reduction in the area of a section and therefore increased stresses in the section, is often the initial cause of cracks. In these cases, elimination of the shrinkage generally takes care of the cracks.

Gates and risers are readily removed with band saws.

FINISHING

One of the important economies to be realized by the use of aluminum alloy castings results from the ease with which they can be finished. The light weight, which facilitates their handling during the finishing operation, the relative smoothness of their cast surfaces and absence of burned-in sand, the non-abrasive character of the metal and relative ease and speed with which the metal can be trimmed and ground—all make for economy in finishing.

Core knockout, chipping, sawing, grinding and polishing are normally done with the standard tools developed for that purpose, although certain modifications in the tool operation may be required for best results with aluminum. The selection of tools and materials depends to some extent on the size and shape of the castings to be finished and nature of the finish required. Therefore, the following recommendations, while based on general practices, may require modification in certain cases to provide the best finishing system for particular plant conditions and casting design.

Removal of cores is the first operation in the finishing of many castings. With aluminum castings, this normally presents few problems other than exercising sufficient care to prevent damage to the castings, particularly while they are hot. A light rapping of the casting and possibly some probing with a bar generally is sufficient to loosen the sand so it will run out of the casting cavities readily. Pneumatic rapping machines for small castings and air hammers for larger castings aid in core-sand removal.

Cores made with certain sand mixtures are more readily removed than others, and their selection is important where cores must be removed from inaccessible pockets. If properly made cores are used, castings should be free of burned-in sand; and hence offer no trouble in removing the last traces of sand from the surfaces.

Trimming a casting with a pneumatic chipping hammer.

Gates and risers that are readily accessible are best removed with band saws. For average work, heavy-duty woodworking saws have been found satisfactory but for heavy work, high-speed metalworking saws are preferred. Such saws are operated at speeds of 3000 to 5000 feet per minute, the speed depending upon the metal section. The heavier the section, the slower the blade speed. The saw-blade width and gauge, as well as tooth pitch, are also controlled by the thickness of section to be cut. Blades up to 1½ inches in width by 16 gauge, with 3 teeth per inch, are common for extremely heavy work. For light work, blades ½ inch by 20 gauge and with up to 8 teeth per inch are used satisfactorily.

Ordinary carbon steel in the spring-tempered condition is generally used for these saws and can be resharpened readily by filing. Such saws should be provided with not more than a 5-degree top rake and about 0.015 inch clearance on each side to minimize heating due to the teeth dragging. Using a saw with too much top rake or hook will cause the saw to feed into the work too rapidly for hand feeding and may result in the blade pulling out of the guides. Wood saws which have teeth with a negative rake should not be used with aluminum. A cutting oil, stick grease or tallow should be used as a coolant and lubricant, particularly for heavy cutting.

Sprue cutters also provide a means of removing gates from accessible locations although often not as cleanly as a saw. Care must be used in keeping such cutters sharp to avoid breaking off a piece of the casting with the gate.

Pneumatic chipping hammers may be used to remove gates and risers that cannot be readily sawed or sheared off. To avoid breaking metal in the casting proper, the preliminary cut should be made a little above the surface. Excess metal then can be removed by later operations. Pneumatic chipping hammers are likewise useful in removing fins and surface irregularities as well as the final traces

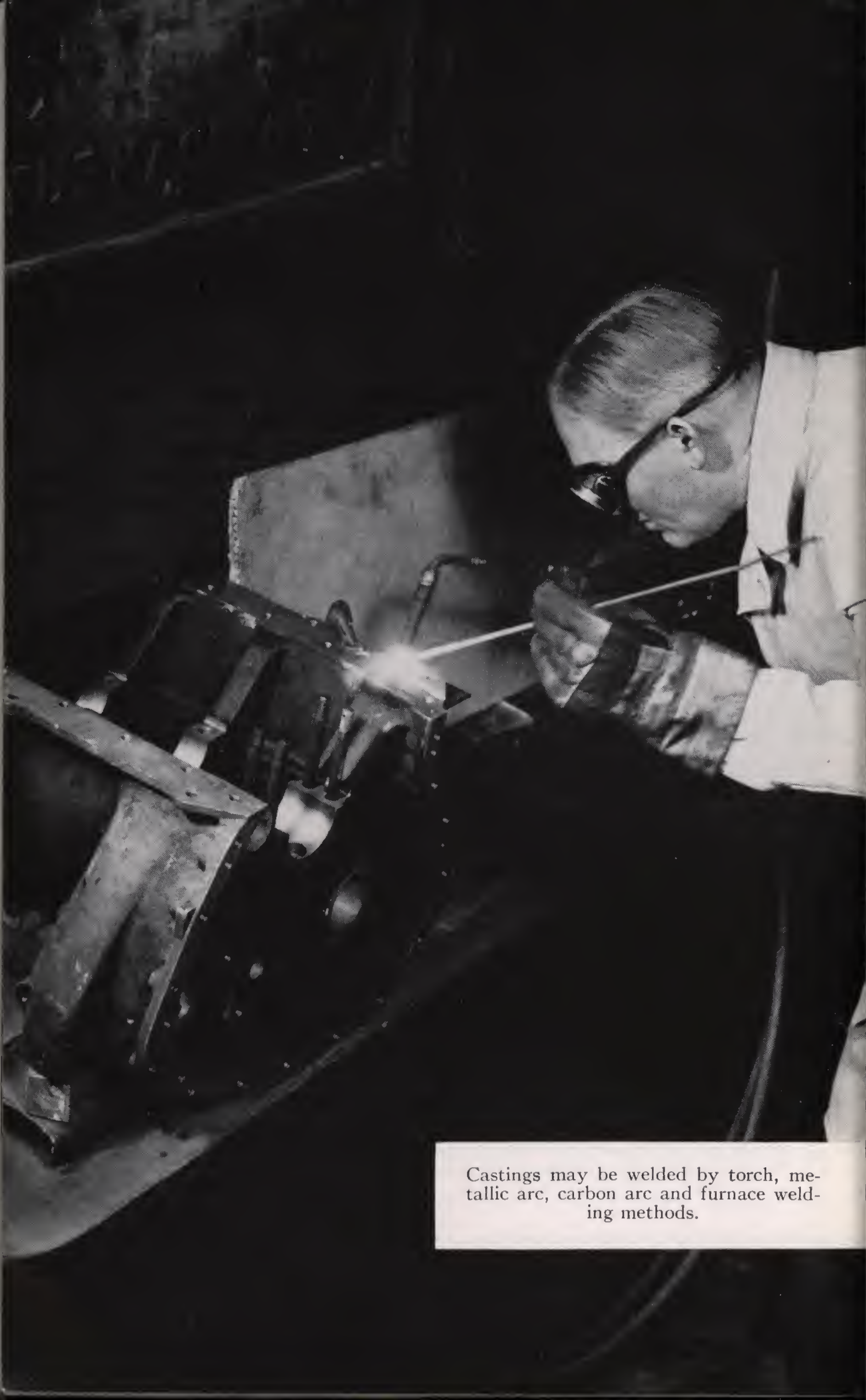
Snagging, rough grinding and polishing of small castings are done on portable and stationary grinders equipped with suitable wheels.

of gates which were cut off by a saw or sprue cutter. By substituting a blunt-nosed tool in place of the chisel, an excellent tool is provided for peening other surface irregularities. A cutting or lubricating oil will be found desirable when using chisels.

The great variety of grinding wheels available for both portable and stationary tools permits considerable flexibility in snagging and grinding operations. For small castings, bonded abrasive wheels, mounted on conventional lathes, are generally satisfactory for rough grinding on external surfaces. Flexible-shaft machines with small burrs or abrasive wheels readily reach the other surfaces.

For large castings, portable air or electrically driven tools are useful for rough grinding. When considerable metal is to be removed, particularly from a flat surface, rotary vertical grinders equipped with bonded abrasive cup wheels are most satisfactory. Flexible abrasive paper disks used with such grinders are better adapted to irregular surfaces. In other cases, wheels built up of muslin or canvas to the required thickness and set up with abrasive glued to the circumference are employed for rough grinding on irregular surfaces.

Type and size of abrasive, type of bond and wheel speed are important considerations in the selection of polishing equipment. Aluminous abrasives from No. 20 to No. 80 are generally preferred for the rough grinding work, their characteristics providing the desired cutting efficiency. Solid wheels with bonded suitable synthetic resin bond and filler are also preferred, although various vitrified bonds are used for some applications. The bond selected should minimize, as much as possible, the tendency for the wheel to become loaded with metal. Muslin or canvas wheels to which the abrasive is attached with glue must be set up with special attention to both composition of glue and methods of application. Manufacturers of both wheels and abrasives are familiar with requirements for aluminum



Castings may be welded by torch, metallic arc, carbon arc and furnace welding methods.

sand castings and can recommend the wheels best suited for any particular operation.

Since aluminum alloys are somewhat softer than many of the other metals, softer abrasives and bonding materials are required. Wheel speeds must therefore be reduced to maintain cutting efficiency and to prevent overheating. For most rough polishing, wheel speeds of 5000 to 8500 surface feet per minute are adequate. In the case of cup wheels and abrasive disks on portable grinders, a grinder speed of 4000 to 5000 revolutions per minute is sufficient. Lubricants such as stick tallow or grease may be used when necessary. These should be used with care to avoid excessive lubricant being driven into the pores of the casting and spotting the surface by seepage during some later finishing operation.

Files are used for final touching up of castings and for cleaning sections that cannot be ground with larger tools. A single deep-cut, coarse, curved-tooth file will remove metal rapidly without loading of the teeth. Similar files with notched teeth which break up the cuttings are even more rapid, but do not produce as smooth a surface. A tooth pitch of 9 to 12 teeth per inch is generally preferred for these files. For smaller work and finish-filing, long-angle lathe files or hand cut files may be used satisfactorily. Files of this type should be provided with 14 to 20 teeth per inch cut with a side rake of 45 to 55 degrees.

Sand or steel grit blasting offers an excellent method for cleaning aluminum alloy sand castings as well as giving a uniform pleasing appearance to the finished part. Surface discoloration, minor surface roughness and roughness from coarse grinding operations can be removed readily or masked by sandblasting. Unsoundness which may be present just below the surface is generally revealed by blasting, which makes this procedure desirable in connection with the final inspection of certain castings.

Welding aluminum alloy castings is a practical procedure providing it is done under controlled conditions. Either oxyacetylene or oxyhydrogen torches or the electric arc, when used with a suitable welding rod and flux, will produce satisfactory welds in the common alloys. Where practical, castings should be preheated before welding to minimize danger of cracking and to facilitate the welding operation. They should likewise be cooled slowly to room temperature after welding. Welded areas should be cleaned carefully to insure complete removal of the welding flux, which is corrosive.

Castings may become warped during knockout or by the stresses set up in them during solidification and cooling. With suitable care even the least ductile of the aluminum alloy castings can be straightened within limits. In many cases, however, particularly with the less ductile alloys and where considerable deformation is required, local heating may be necessary.

Castings for ornamental and architectural applications, for which aluminum is ideally suited, can be supplied with a number of attractive finishes. These finishes are applied by either mechanical, chemical or electrochemical means. Their successful application depends to some extent on the shape and alloy composition of the object to be finished, as well as the skill of the operator, making it necessary to work out the most efficient system for each individual part.

Sandblasting is a rapid and inexpensive means of applying a pleasing matte finish to aluminum alloy castings, although this finish has the disadvantage that it fingerprints easily and is difficult to clean. Application of a lacquer or clear varnish coating makes it easier to wash off fingerprints or dirt which in time collect on rough sandblasted surfaces. The sandblasting of aluminum alloy castings requires much the same equipment as that used for other metals.

TABLE 2

Ornamental Finishing Procedures for Aluminum Castings

Operation	Polished Finish	Buffed Finish	Satin Finish (Compound)	Satin Finish (Wire Brush)
1	*Roughing*—Stitched rag wheel—46 mesh and then 80 mesh fused aluminum oxide—wheel speed of 6,000 surface feet per minute.			
2	*Oiling*—Stitched rag wheel—120 mesh and then 140, 180 or 220 mesh emery—wheel speed of 6,000 surface feet per minute—tallow or mineral grease lubricant.*	*Oiling*—Stitched rag wheel—120 mesh and then 180 mesh emery—wheel speed of 6,000 surface feet per minute—tallow or mineral grease lubricant.	Same as for buffed finish	*Sandblasting*—50 mesh silica sand.
3	. . . .	*Buffing*—Stitched muslin buff—Tripoli grease cake—wheel speed of 7,000 surface feet per minute.	*Satin Finishing*—Unstitched muslin buff—greaseless satin finishing compound—wheel speed of 3,000 surface feet per minute.	*Wire Brushing*—Stainless steel or German silver wire wheel—0.015 inch dia. wires—wheel speed of 1,500 surface feet per minute.
4	. . . .	*Color Buffing*—Unstitched muslin buff—lime or soft silica grease cake—wheel speed of 7,000 surface feet per minute.	. . . .	. . . .

*Stop at abrasive giving desired surface.

Mechanical finishes produced by polishing, buffing or satin finishing can be applied with the ordinary types of polishing equipment. General procedures for applying these finishes are outlined in Table 2. Other desirable finishes may be obtained with rotating wire brushes, fiber bristle brushes or hand rubbing.

For certain applications, electroplated finishes are desired. Methods for applying such plated finishes as nickel, copper, zinc and chromium to aluminum alloys are available and are being regularly used. Care should be taken to select the type of alloy and plate best suited to the particular job. Generally, electroplated coatings find their best possibilities for parts not subjected to continuous outdoor exposure or other severe conditions.

Anodic oxidation treatment is often used as a means of finishing certain aluminum alloy castings. The best process for the application of an oxide finish is known by the registered trademark Alumilite. The oxide coating produced by an Alumilite treatment possesses, in addition to a definite protective value, remarkable resistance to abrasion and electrical insulating properties and makes an excellent base for paint or enamel. These coatings are also very absorbent at one stage of processing and can be readily impregnated with dyes or mineral pigments for decorative color effects and with special agents to increase the resistance of the casting to corrosion.

Further details relative to the various finishing procedures for aluminum alloy castings are found in the booklets listed below. These booklets may be obtained on request from the nearest sales office of Aluminum Company of America.

Machining Alcoa Aluminum
Welding and Brazing Alcoa Aluminum
Finishes for Aluminum

Design of Aluminum Alloy Castings

CERTAIN important factors, if properly considered during the design of aluminum alloy castings, will aid in obtaining higher quality and greater economy. Although the discussion of these factors applies especially to aluminum alloy sand castings, some comments also apply to aluminum alloy permanent-mold and die castings.

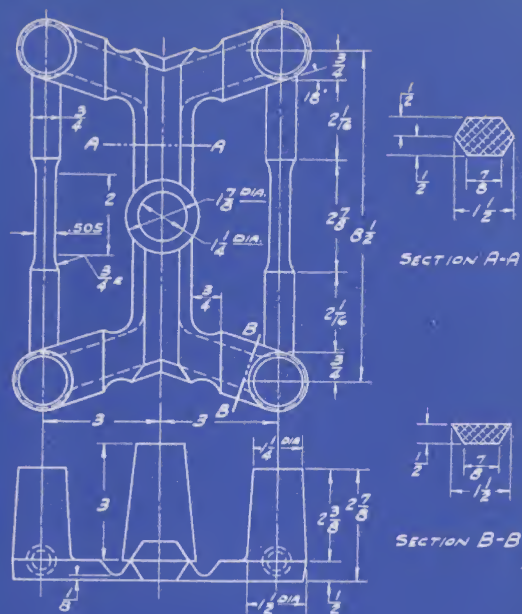
MECHANICAL PROPERTIES

The mechanical properties of Alcoa aluminum casting alloys, as given in Tables VII, VIII and IX of the Appendix, have been obtained from standard A.S.T.M. ½-inch diameter test specimens, separately cast and tested without machining the gauge section, unless otherwise noted. The specimens are cast under standard conditions which duplicate as closely as possible the conditions of solidification of the castings. When cast under such conditions, the test specimens serve as a control of metal quality.

The properties of separately cast test specimens do not necessarily represent the properties of commercial castings, and may be either higher or lower, depending on a number of factors that influence the solidification rate of the metal in the mold.

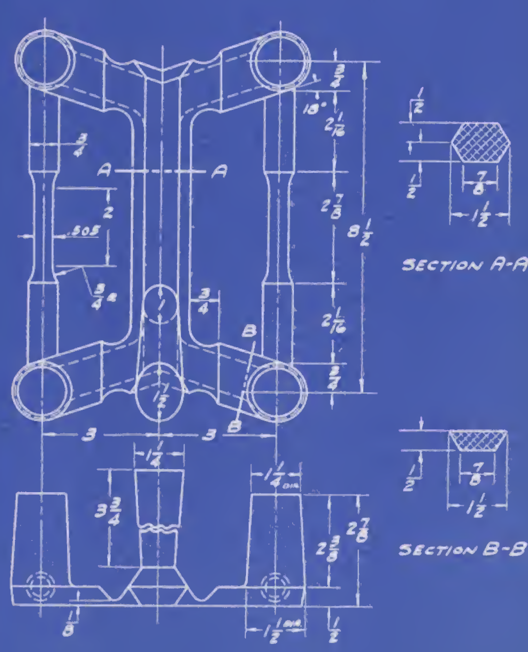
For the same reason, the properties of test specimens machined from a single casting vary, depending on the location from which they are taken. Such foundry considerations as section thickness, gating and risering, chilling, pouring temperature, permeability and moisture content of the sand, and any other factors which influence the rate

Center Vertical Sprue Type



TWO-BAR TEST BAR PATTERNS

End Slanting Sprue Type



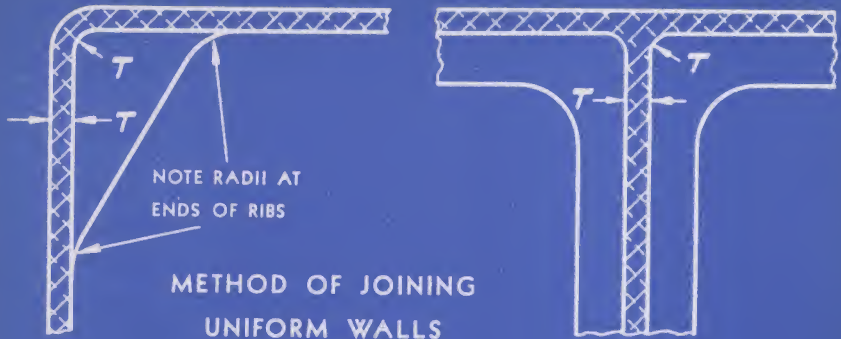
of metal solidification have a material effect on the mechanical properties of the casting.

These relations are not peculiar to aluminum alloy castings, but exist in castings of all metals. They introduce two specific problems for the designer of cast metal parts: first, selection of the proper alloy considering foundry characteristics and physical properties; and second, selection of the proper factor to apply to the properties specified for an alloy in determining the design stress. Such factors must take into account the kind of service for which a casting will be used, as well as the variation in the properties of the sections of each commercial casting. There is no general rule by which these factors can be determined. Most designers develop their particular methods from experience with specific metals and types of castings, and proof load or breakdown tests on castings under service loading conditions provide data which are extremely useful in this connection if either the design or application of the casting is new. The latter method, particularly, is finding favor as a means of checking a design.

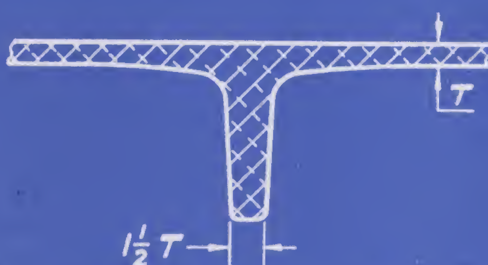
DRAFT AND SHRINKAGE

Regardless of the type of pattern equipment, draft and shrinkage requirements must be taken into account in design. Sufficient draft or taper should be provided on all vertical faces of the pattern to permit its removal from the mold. Pattern drawings should state specifically whether to add or subtract this draft from the casting dimension.

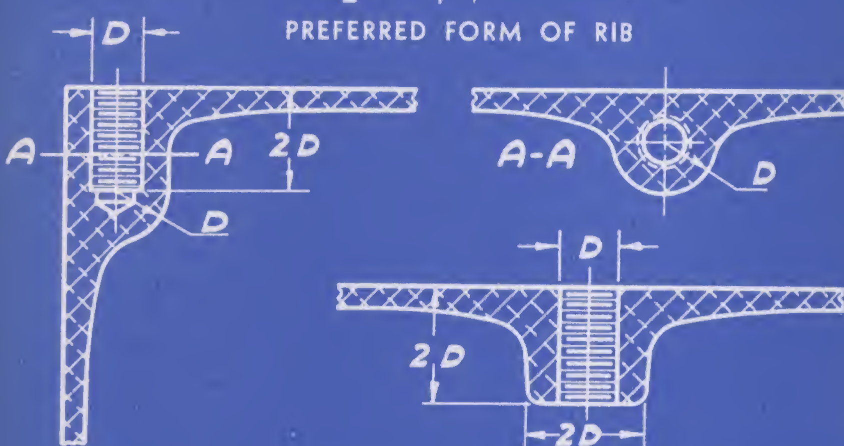
The casting shrinkage for aluminum alloys is usually given as $\frac{5}{32}$ inch per linear foot, which is correct for average size castings made in green sand. The total amount a casting will contract, however, depends largely on its size, shape and method of molding (Table XI, Appendix). For castings made in metal molds the shrinkage allowances must be determined by experience.



METHOD OF JOINING
UNIFORM WALLS



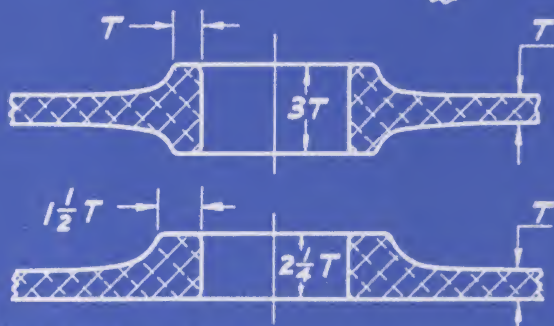
PREFERRED FORM OF RIB



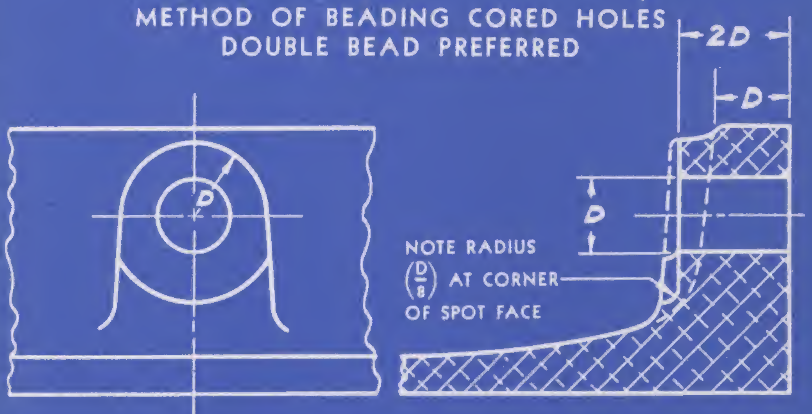
METHODS OF BLENDING METAL AROUND BOLT BOSSES

DETAILS OF CASTING DESIGN

METHOD OF JOINING
THIN AND THICK WALLS



METHOD OF BEADING CORED HOLES
DOUBLE BEAD PREFERRED



RECOMMENDED FLANGE AND BOLTHOLE PROPORTIONING

DETAILS OF CASTING DESIGN

PARTING LINE AND JIG LOCATIONS

Parting lines should be made as even as possible to facilitate molding and decrease molding costs. As an aid in checking the finished casting, center lines may be scratched deeply enough on the pattern to show on the resulting casting.

Jig spots to be used by the machine shop should be clearly marked on the pattern drawing so that both machine shop and foundry will check the castings from the same points. These spots are located with respect to the outside wall of the casting where they will not be influenced by cored faces which might change with normal variations in the setting of the cores. For most accurate results, they should be as far apart as the casting size permits. Marking jigging points on the blueprint will also aid the foundryman in placing gates, risers and chills.

MOLDING AND CORING

Many molds and cores now being made of dry sand might have been made of green sand had the idea been considered in the original casting design. From the standpoint of economy, green sand is desirable wherever satisfactory. When using green sand, especially for cores, ample provision must be made for support in the mold since it has less strength than dry sand.

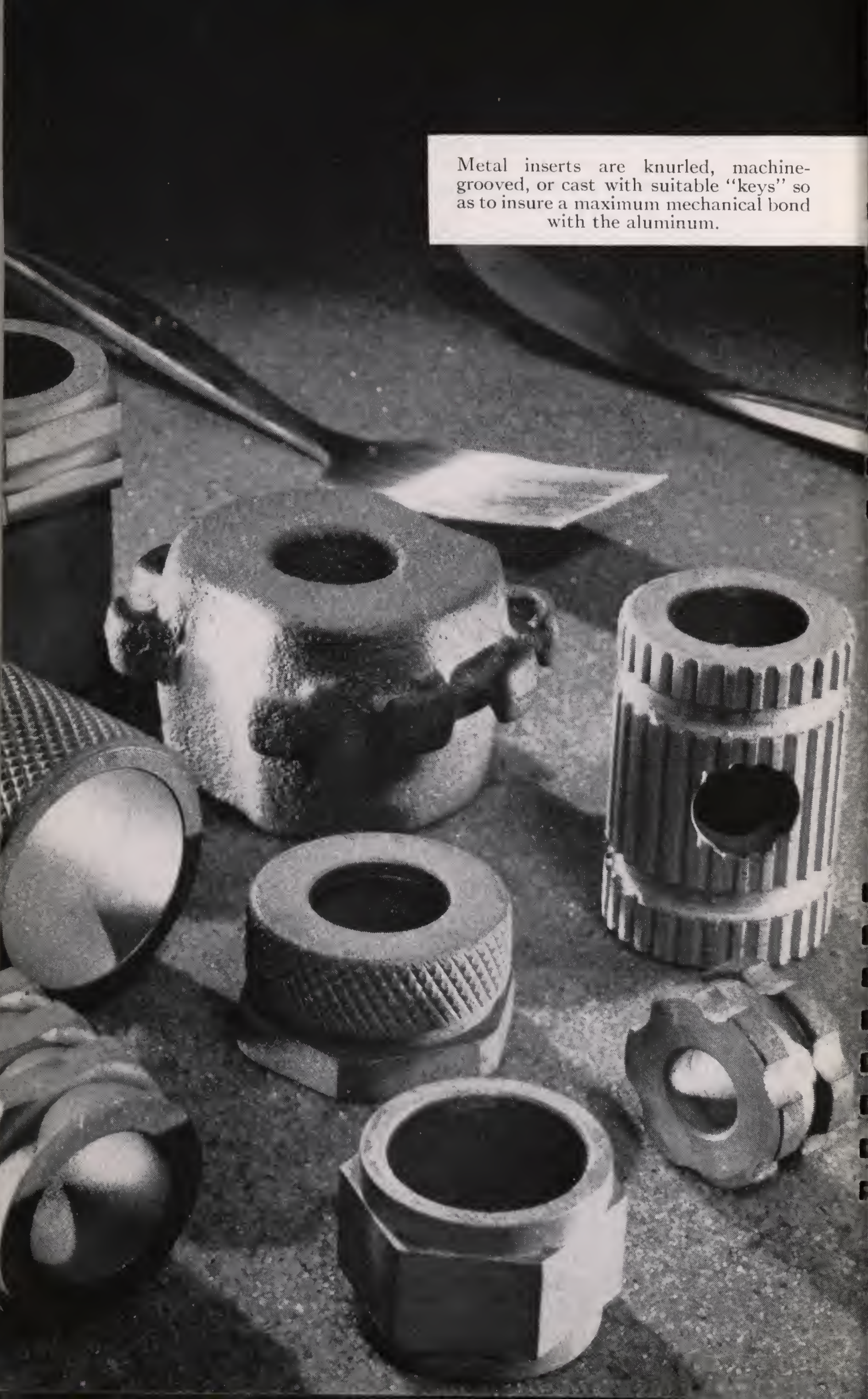
Regardless of whether a core is made in green or dry sand, there are certain factors to be considered in its design, as well as in design of the casting as a whole. Cores should be of sufficient thickness to be easily handled without excessive breakage. If possible, it is desirable to eliminate projecting and overhanging parts, which are easily broken or washed away by the metal.

Core prints should be designed of sufficient size not only to give a suitable support to the cores, but also to permit easy escape of the mold gases developed when the core is surrounded by molten metal. They should be so located as to support the core uniformly and prevent it from shifting and sagging. In particular cases, especially when pressure tightness in the casting is required, additional core prints are desirable to remove core gases, which may cause porosity and blows. Core prints should be large enough to permit easy removal of strengthening wires and chills.

A design which requires setting cores in sections, resulting in fins on the castings, should be avoided, especially when such fins are located where they cannot be removed. Whenever possible, cores should also be designed so they can be dried on a flat surface. Otherwise, core driers should be specified to facilitate production and prevent sagging or warping during handling and drying.

Chaplets for supporting cores are sometimes desirable, but must be used with discretion. They are not satisfactory in castings which are to be pressure tight since leakage will usually occur around them. In long cores which require intermediate supports, core prints are more suitable. In this case, the resulting hole may later be filled with a threaded plug. If core prints are in a highly stressed section, a bead is desirable around the hole to compensate for loss in section area.

Either aluminum or steel chaplets may be used in thin sections, while in thick sections or for support of heavy cores, steel chaplets are more suitable. If not properly coated to prevent attack by the molten aluminum, steel chaplets will sometimes cause a segregation of a high-iron alloy around them and appreciably lower the strength of the section. A whiting wash similar to that used on iron melting pots is sometimes employed as a protective coating, care being taken to insure a thin uniform coating so the chaplets will not become loose in the casting.



Metal inserts are knurled, machine-grooved, or cast with suitable "keys" so as to insure a maximum mechanical bond with the aluminum.

INSERTS

It is often desirable to cast inserts of other metals in aluminum sand castings. Cast iron or steel are the most suitable materials, although copper is sometimes used when proper care is taken to prevent solution in the aluminum. Brass and high lead bronze inserts should be avoided, as they will dissolve partially or wholly in the molten aluminum if not suitably protected.

Because other metals have different coefficients of expansion from those of aluminum alloys, the economical use of inserts requires a definite foundry technique. Depending on the size and design of the casting, some inserts must be preheated and inserted in the mold hot, while others can be used after thorough torch drying in the mold. Preheating to burn off oil and sandblasting to remove dirt and scale materially aid in preventing blows around the inserts. Placing of risers near inserts or coating inserts with core oil and drying the oil aids in preventing blows. To eliminate cracks during solidification, sufficient metal must be provided around inserts to withstand the stress developed as the aluminum shrinks. Also, to insure maximum mechanical bond to the aluminum, inserts should be knurled on the surface or machine-grooved or cast with suitable "keys." Choice of surface preparation will depend on both size and shape of insert.

SECTION THICKNESS

From a foundry standpoint, it is desirable to maintain uniform sections throughout a casting. Section uniformity helps not only to simplify the gating and feeding problem, but also to equalize the rate of solidification, an important factor in controlling the quality of castings. Variations in section tend to set up internal strains in the casting and cause non-uniform solidification, which may result in shrinkage and cracking. When it is necessary to use a design in which light and heavy sections join, a gradual

increase in thickness of the thinner section toward the point of junction is an advantage.

It is difficult to specify a minimum section thickness that can be cast in aluminum, because it depends very materially on the size, pressure requirements and intricacy of the casting. Although sections as thin as $\frac{1}{8}$ inch have been satisfactorily made in small sand castings, $\frac{3}{16}$ inch is generally considered the minimum for small and medium-size castings.

Both the low specific gravity of aluminum alloys and pouring-temperature considerations limit the size of sections that can be satisfactorily cast. Since the temperature at which a casting is poured affects the resulting physical properties, the casting should be designed to permit as low a pouring temperature as possible. The designer should remember that the pouring temperature is governed by the thinnest section in a casting and its location with respect to the gates through which the molten metal enters.

DESIGN OF RIBS

Section-thickness limitations also apply to the design of ribs. Thin ribs, particularly those highly stressed, should be given considerable attention since their rapid cooling in the mold may set up casting strains and result in a lowering of the strength of the casting and possibly in cracks. Whenever practical, a casting should be designed so that it can be molded with the ribs projecting into the drag or bottom part of the mold. This precaution will reduce the danger of the strength being affected by dross and dirt accumulating in the edges of the ribs.

Rib edges should be square, rather than "rounded," in order to reduce outer fiber stresses and thus minimize the danger of cracking. Beads added to rib edges will further reduce these stresses and improve the strength. This latter practice is desirable when addition of the bead does not complicate the molding too greatly.

FILLETS

Generous fillets at all angles help to prevent shrinkage and cracking at these points. Sharp angles from any cause are to be avoided as they, too, constitute a source of weakness in the casting. Ribs, in particular, must be well filleted into the supporting faces of the casting, because it is in such sections that many foundry defects occur. Similar considerations likewise apply to core design.

MACHINE FINISH ALLOWANCE

The amount of finish allowance necessary on different parts of a casting varies widely, depending on its size, method of machining and type of finish desired. Castings to be finished from the rough by grinding or filing require but little finish allowance; in many cases rapping the pattern during molding provides sufficient allowance. For small and medium-size castings to be finished in a lathe, planer or milling machine, 1/8 inch will provide enough metal. Large castings usually require 1/4-inch finish allowance, but larger finish allowances may be needed on the cope surfaces of some large castings.

Whenever possible, surfaces which are to be machined should be cast in the drag since there is less chance of imperfections being present in these surfaces than in cope surfaces. When conditions require the casting of such surfaces in the cope, an extra finish allowance may be required to permit machining down to the sound metal.

PATTERN EQUIPMENT

Pattern equipment for use in production of aluminum alloy castings is not unlike that used for production of castings in other alloys. This does not mean, however, that such equipment designed for use with brass, bronze, iron or steel can always be used for the production of aluminum alloy castings, since very often the difference in physical

properties between these materials necessitates compensating changes in various sections of the casting. Different molding conditions also usually require a change in gating to adapt such a pattern to aluminum foundry practice. The extent of these changes will depend, of course, upon the particular requirements of the casting. Reference has been made to the shrinkage allowance for patterns for aluminum alloy castings. The fact that this value is different for various casting materials may make patterns designed for other materials unsuitable for aluminum alloy castings.

Description of Alloys

THIS CHAPTER lists the common Alcoa aluminum casting alloys available in ingot form. They are arranged according to their major alloying constituents, and their characteristics and typical uses are tabulated. Similar data for the heat-treatable Alcoa casting alloys may be found in "Alcoa Aluminum and Its Alloys" or obtained from any of the sales offices listed on page 94.

Index of Alloys*

*The above index and following description do not include casting alloys A132, 195, B195, 213, A213, B213, 220, 355, and 356. The composition of these newly added alloys may be found on page 76.

Aluminum-Copper Alloys

Alloy No.	Nominal chemical composition, per cent (balance aluminum)
81	7.0 Copper 3.0 Silicon
112	7.0 Copper 1.2 Iron 1.7 Zinc
B113	7.0 Copper 1.2 Iron 1.7 Silicon
C113	7.0 Copper 1.2 Iron 3.5 Silicon 2.0 Zinc
122	10.0 Copper 1.2 Iron 0.2 Magnesium
172	8.0 Copper 2.5 Silicon
212	8.0 Copper 1.0 Iron 1.2 Silicon

THE aluminum casting industry in America has developed around the alloys in which copper is the principal hardening constituent. Additions of up to 12 per cent copper progressively increase the strength and hardness of the resulting alloy, but the ability of alloys containing over 8 per cent copper to withstand suddenly applied loads or shock is comparatively low. Although the tensile properties of the 8 per cent copper casting alloys are very similar, the original binary alloy (generally known as No. 12) has been almost completely replaced by alloys such as Alcoa 112 and 212 with controlled additions of certain other elements. Alcoa alloy 112 provides better machining characteristics, and Alcoa alloy 212 better casting characteristics than the older binary alloy. Both alloys provide adequate strength for many applications where high impact loading is not encountered.

The choice among the aluminum-copper sand-casting alloys

Outstanding characteristics	Uses
Satisfactory mechanical properties and casting characteristics for simple castings with sections of moderate thickness.	*Die castings:* small, less intricate parts.
Good casting and machining characteristics.	*Sand castings:* automotive crankcases, oil pans, manifolds, transmission housings, miscellaneous general-purpose machine castings.
Good casting characteristics and machining properties.	*Permanent-mold castings:* washing machine agitators, vacuum cleaner housings, general-purpose castings.
Modification of alloy B113 providing better pressure tightness.	*Permanent-mold castings:* automotive cylinder heads, general-purpose castings with pressure requirements.
Retains strength well at elevated temperatures. Good hardness, machinability and wear resistance.	*Permanent-mold castings:* automotive pistons, pump housings. *Sand castings:* air-cooled cylinder heads, pistons.
Excellent casting characteristics, small solidification shrinkage.	*Sand castings:* match plates, metal patterns.
Improved foundry characteristics over alloy 112, and less hot short.	*Sand castings:* general-purpose castings of intricate design.

is largely a matter of foundry experience, each being capable of producing the general run of castings. Alloys 212 and 172, which have higher silicon contents than alloy 112, are generally favored for extremely thin-sectioned castings because of their superior fluidity. Alcoa alloys B113 and C113, which are similar to alloys 112 and 212, were developed particularly for permanent-mold casting work. An alloy of the same general type, Alcoa alloy 81, is used for small die castings of relatively simple design. Both sand and permanent-mold castings, which must retain their strength well at elevated temperatures or require good hardness and wear resistance, may be made of alloy 122.

All these alloys machine well. However, aluminum-copper alloys are not so resistant to corrosion, nor do they take anodic coatings that are as thick and as abrasion-resistant as the aluminum-silicon and aluminum-magnesium alloys.

Aluminum-Silicon Alloys

Alloy No.	Nominal chemical composition, per cent (balance aluminum)
13	12.0 Silicon
43	5.0 Silicon
45	10.0 Silicon
47	12.5 Silicon

Because of their excellent casting characteristics, aluminum-silicon alloys have found increasing commercial use. Both the fluidity and freedom from hot shortness of these alloys increase with silicon content up to about 12 per cent, which is approximately the eutectic composition. The alloys also are quite fluid at temperatures down almost to the solidification temperature. Their excellent casting characteristics make aluminum-silicon alloys especially desirable for many sand, permanent-mold and die castings.

These alloys have a greater tendency to absorb iron when liquid than do aluminum-copper alloys. Therefore because of the harmful effect of iron on physical properties of the cast alloy, it is necessary to use care in melting to keep contamination at a minimum.

It is possible, by using aluminum-silicon alloys, to produce without undue difficulty, intricate castings consisting of thick and thin sections. It is also somewhat easier to make castings free from leaks with these alloys than with most other aluminum alloys. As a result, they are used for parts which must be leak-proof under either vacuum or pressure.

Aluminum-silicon alloys are resistant to corrosion, hence are especially suited for marine work and other uses requiring this quality. In severely corrosive environments an Alumilite finish,

Outstanding characteristics	Uses
Excellent casting characteristics and very good resistance to corrosion. Good mechanical properties.	*Die castings:* general-purpose alloy for large intricate parts.
More ductile and resistant to shock than aluminum-copper alloys. Excellent casting qualities and pressure tightness, very good resistance to corrosion.	*Sand castings:* architectural and ornamental parts, pipe fittings, cooking utensils, food handling equipment, marine fittings. *Permanent-mold castings:* cooking utensils, general-purpose castings of thin sections. *Die castings:* general-purpose castings.
Slightly higher strength and hardness than produced by alloy 43.	*Sand castings:* instrument cases, miscellaneous fittings and housings.
Modified silicon alloy with very good mechanical properties and resistance to corrosion.	*Sand castings:* general-purpose castings requiring strength and ductility in excess of that provided by other common alloys.

supplemented by a dichromate impregnation of the oxide film, makes the castings much more resistant to attack.

Alloys of this class can be satisfactorily machined although not as readily as many of the other casting alloys of aluminum. However, large quantities of silicon-alloy castings requiring machining are in daily production in many plants. Machining is simplified by using proper technique, tools and lubricants as described in the booklet "Machining Alcoa Aluminum," available on request to any of our sales offices.

By the use of special foundry methods, it is possible to use a silicon content even higher than the normal eutectic composition and obtain sand castings which have an extremely fine grain structure, high strength and good elongation. This type of alloy is called a "modified" silicon alloy, while castings poured without special treatment are called "normal." The benefits of the modification process are largely lost on remelting, a retreatment of the melt being necessary if the resulting sand castings are to have the properties of the modified alloy. The chemical modification treatment is not required on high silicon alloys used for the production of die castings; modification in this case results from the rapid solidification of the metal.

Aluminum-Copper-Silicon Alloys

Alloy No.	Nominal chemical composition, per cent (balance aluminum)
83	2.0 Copper 3.0 Silicon
85	4.0 Copper 5.0 Silicon
108	4.0 Copper 3.0 Silicon
A108	4.5 Copper 5.5 Silicon
A334	3.0 Copper 4.0 Silicon 0.3 Magnesium

ALLOYS containing both copper and silicon as hardeners combine some of the desirable qualities of the aluminum-copper and the aluminum-silicon alloys. Because of their silicon content, they have better casting characteristics than alloys of the No. 12 type, and because of their copper content, they have better mechanical properties and machining qualities than alloy 43. Their resistance to corrosion is better than that of aluminum-copper alloys, but inferior to that of aluminum-silicon alloys.

Aluminum-copper-silicon alloys, because of their good casting

Outstanding characteristics	Uses
Good casting characteristics and ductility.	*Die castings:* parts requiring spinning, swedging, bending or other forming operations.
Best combination of strength and ductility of alloys in this group. Casts well in thick sections.	*Die castings:* brackets, frames and levers with thick sections.
Better casting characteristics and more pressure tight than aluminum-copper alloys.	*Sand castings:* manifolds, valves and other intricate castings requiring pressure tightness.
Good casting characteristics.	*Permanent-mold castings:* ornamental grilles and general-purpose castings.
Better tensile properties than alloys 108, 112 and 212.	*Sand castings:* automotive engine parts, air brake valves and other intricate castings requiring pressure tightness.

characteristics, can be used for castings of intricate design as well as those requiring pressure tightness. Castings which have extremely large differences in section thickness are more readily cast in these alloys than in aluminum-copper alloys. The choice of alloy depends largely on the mechanical properties required since the other characteristics are about the same.

Certain of the aluminum-copper-silicon alloys are used extensively for the production of die castings, while the other alloys of this group are suitable for sand or permanent-mold castings.

Aluminum-Magnesium Alloys

Alloy No.	Nominal chemical composition, per cent (balance aluminum)
214	3.8 Magnesium
A214	3.8 Magnesium 1.8 Zinc
B214	3.8 Magnesium 1.8 Silicon
218	8.0 Magnesium

Aluminum-magnesium alloys have an excellent combination of mechanical and chemical properties; they are particularly resistant to corrosion and tarnish. In this latter respect, alloys 214, B214 and 218 are considerably superior to practically all other common sand-casting alloys of aluminum.

Alloys of this group have certain characteristics which differ from those of most aluminum alloys and require an exacting foundry technique. For example, they have a marked tendency to oxidize. Excessive oxidation during remelting can be prevented by carefully controlling the melting and pouring practice. It is also frequently desirable to flux the molten metal to reduce the oxidation loss and aid in removal of dross (see page 27).

Aluminum-magnesium alloys also have a narrow solidification range. Compensation for this characteristic can be made by careful location of gates, chills and risers so as to insure progressive feeding. Heavier chilling and more thorough feeding than are necessary with other aluminum alloys are required to

Outstanding characteristics	Uses
Excellent resistance to corrosion and tarnish and excellent combination of mechanical properties. Not pressure tight.	*Sand castings:* dairy and food handling equipment, cooking utensils, fittings for chemical and sewage use, hardware, ornamental housings.
Variation of alloy 214 for permanent-mold work. Good resistance to corrosion and tarnishing.	*Permanent-mold castings:* cooking utensils.
Improved foundry characteristics over alloy 214, but reduced mechanical properties. Excellent resistance to corrosion.	*Sand castings:* same as for alloy 214 where improved casting characteristics are required. *Permanent-mold castings:* cooking utensils and pipe fittings for marine as well as general use.
Excellent resistance to corrosion and tarnish as well as excellent strength and ductility. Does not cast as well in intricate parts as alloy 13.	*Die castings:* fittings for marine use, hardware, and castings requiring high strength, ductility and resistance to corrosion.

obtain castings with maximum soundness. The gating should be carefully designed to prevent, as much as possible, the formation of dross and to exclude from the mold that which is formed. The use of rectangular sprues and a pouring basin over the sprue on the top of the mold reduces agitation. Cutting a runner of triangular cross section in the cope over the drag runner and controlling the size of the gates from the runner to the casting minimize the tendency for dross formed during pouring to enter the mold cavity.

The aluminum-magnesium alloys are more difficult to cast into intricate leakproof parts and cannot be welded as satisfactorily as most of the other aluminum alloys.

These alloys all respond very well to finishing by the Alumilite process, which gives alloys 214, A214 and 218 a light-colored appearance and blends well with similarly finished wrought material. Alloy B214, because of its silicon content, is slightly gray in color after being finished by the Alumilite process.

Alloy No.	Nominal chemical composition, per cent (balance aluminum)
Aluminum-Zinc Alloy	
645	2.5 Copper 1.2 Iron 11.0 Zinc
Aluminum-Copper-Nickel-Magnesium Alloy	
142	4.0 Copper 1.5 Magnesium 2.0 Nickel
Aluminum-Manganese Alloy	
406	2.0 Manganese

Aluminum-Zinc Alloys

In England, the aluminum sand-casting industry has developed around the use of aluminum-zinc alloys, with the result that they occupy a position similar to that held by aluminum-copper alloys in America.

Alloys of this type, although they develop quite interesting mechanical properties, age rapidly at room temperature with a substantial reduction in ductility. For certain applications, however, particularly where high impact loading is not encountered, such alloys are used quite satisfactorily.

Alcoa alloy 645 is an alloy of this general type providing a combination of mechanical properties intermediate between those of the common aluminum-copper and aluminum-silicon alloys and the heat-treated alloys.

* * *

Aluminum-Copper-Nickel-Magnesium Alloy

Alcoa alloy 142 ("Y" alloy) containing copper, nickel and magnesium is most frequently used for castings that must retain

Outstanding characteristics	Uses
High strength and ductility. Ductility reduced appreciably on room temperature aging. Greater shrinkage tendency than aluminum-copper alloys.	*Sand castings:* miscellaneous general-purpose castings.
Good strength at elevated temperatures. Good bearing characteristics.	*Sand castings:* pistons and air-cooled cylinder heads. *Permanent-mold castings:* pistons for Diesel and gasoline engines.
Excellent resistance to corrosion. Largely superseded by alloys 43 and B214 because of their better casting properties.	*Sand castings:* pipe and tank fittings.

their strength well at elevated temperatures or in which good bearing characteristics are required. It has some of the foundry characteristics of aluminum-magnesium alloys, and should be carefully handled in the foundry for most satisfactory results. This alloy is less desirable than aluminum-silicon or aluminum-silicon-copper alloys for castings requiring freedom from leaks, particularly when they are of relatively thin sections.

* * *

Aluminum-Manganese Alloys

ALUMINUM-MANGANESE ALLOYS find only limited application today, having been replaced to a large extent by alloys containing silicon and magnesium, which have superior combinations of properties. One aluminum-manganese alloy, known as Alcoa alloy 406, has excellent resistance to corrosion and high ductility, but is somewhat difficult to cast because of its marked shrinkage tendency. It has been used for pipe fittings because of its high resistance to slightly acid solutions and its similarity in composition to the wrought alloy 3S usually used for pipe.

MISCELLANEOUS CASTING ALLOYS

A NUMBER of aluminum alloys have been developed for particular applications where some specific characteristics are desired. The services of the engineering and technical staffs of Aluminum Company of America are available on request to assist in selection of both standard and special alloys for casting applications.

In certain castings for electrical appliances, controlled electrical conductivity is required, particularly in conductor bars for the rotors of induction motors. Many such bars are cast integral with the collector rings and cooling fans, using aluminum alloys and some pressure-casting method. When maximum conductivity is desired, commercially pure aluminum is generally used. For certain rotor designs, however, the casting characteristics of Alcoa alloy 315 are more suitable. It contains 1.5 per cent silicon which, though reducing the conductivity slightly, materially improves the casting properties.

Where low electrical conductivity is necessary, use is made of Alcoa alloy A254 which contains 6 per cent magnesium, 1.5 per cent manganese and 1.5 per cent nickel. Having the same general casting characteristics as other aluminum-magnesium alloys, it requires similar handling for best results.

Alloy 47 (see aluminum-silicon alloys) is also used for rotor work, its excellent casting characteristics offering a material advantage for certain small, intricate castings. This alloy provides electrical conductivities intermediate between those of pure aluminum and alloy A254.

Alloy 505, containing 4.5 per cent nickel, is particularly suited for die-cast burners for domestic gas ranges, which require a bright appearance and better resistance to softening at elevated temperatures than is provided by the more common alloys.

Appendix—Tabular Data

Index to Tabular Data

TABLE I

Nominal Composition of Alcoa Casting Alloys

Standard Ingot Sizes*

Alcoa Alloy No.	Per Cent of Alloying Elements Aluminum and Normal Impurities Constitute Remainder						
	Copper	Iron	Silicon	Zinc	Manganese	Magnesium	Nickel
SAND-CASTING ALLOYS							
43	...	...	5.0	...	...	...	...
45	...	...	10.0	...	...	...	...
47	...	...	12.5	...	...	...	...
108	4.0	...	3.0	...	...	...	...
112	7.0	1.2	...	1.7	...	...	...
122	10.0	1.2	...	...	...	0.2	...
142	4.0	...	...	...	...	1.5	2.0
172	8.0	...	2.5	...	...	...	...
195	4.0	...	...	...	...	...	...
212	8.0	1.0	1.2	...	...	...	...
213†	...	...	...	...	...	3.8	...
B213†	...	...	1.8	...	...	3.8	...
214†	...	...	...	...	...	3.8	...
B214†	...	...	1.8	...	...	3.8	...
220	...	...	...	...	...	10.0	...
A334	3.0	...	4.0	...	...	0.3	...
355	1.3	...	5.0	...	...	0.5	...
356	...	...	7.0	...	...	0.3	...
406	...	...	...	...	2.0	...	...
645	2.5	1.2	...	11.0	...	...	...
PERMANENT-MOLD CASTING ALLOYS							
43	...	...	5.0	...	...	...	...
A108	4.5	...	5.5	...	...	...	...
B113	7.0	1.2	1.7	...	...	...	...
C113	7.0	1.2	3.5	2.0	...	...	...
122	10.0	1.2	...	...	...	0.2	...
A132	0.8	...	12.0	...	...	1.0	2.5
142	4.0	...	...	...	...	1.5	2.0
B195	4.5	...	2.5	...	...	...	...
A213†	...	...	...	1.8	...	3.8	...
A214†	...	...	...	1.8	...	3.8	...
355	1.3	...	5.0	...	...	0.5	...
356	...	...	7.0	...	...	0.3	...
DIE-CASTING ALLOYS							
13	...	...	12.0	...	...	...	...
43	...	...	5.0	...	...	...	...
81	7.0	...	3.0	...	...	...	...
83	2.0	...	3.0	...	...	...	...
85	4.0	...	5.0	...	...	...	...
218	...	...	...	...	...	8.0	...
A254	...	...	...	...	1.5	6.0	1.5
315	...	...	1.5	...	...	...	...
505	0.5	...	0.5	...	...	...	4.5

*Available in one of the standard ingot sizes shown on pages 78 and 79.

†Impurities are more closely controlled in the 214 than in the 213 series of alloys. Special foundry technique is required to produce castings of 214, A214, B214 alloys.

TABLE II-A

Nominal Composition of Alcoa Aluminum Ingot and Aluminum Rich Alloy Ingot

Alcoa Alloy No.	Form	Per Cent of Alloying Elements (Aluminum Content Includes Normal Impurities)					
		Aluminum	Copper	Silicon	Nickel	Iron	Titanium
99% Plus	Std. Ingot	99*	..	..	..	..	...
2107	Lump	60	40	..	..	..	...
2309	Std. Ingot	85	..	15	..	..	...
2508	Std. Ingot	75	..	..	25	..	...
2800	Std. Ingot	90	..	..	..	10	...
2806	Lump	50	..	..	..	50	...
2904	Lump	97.5	..	..	..	..	2.5

*Minimum aluminum content. Normal impurities constitute remainder.

TABLE II-B

Approximate Composition of Alcoa Aluminum Pig and Aluminum Rich Alloy Pig

"Pig" is unrefined aluminum of variable composition as cast from the electric reduction furnaces. It can be supplied only in the standard grades listed below.

Alcoa Standard Aluminum Pig Grades

Grade	Form
99% minimum (average)	One size only—1 piece—approximately 50 pounds
99.75% minimum (average)	
99.8% minimum (average)	
99.85% minimum (average)	
99.9% minimum (average)	
94% to 99%	

Shipments of any one of the standard grades listed above may contain individual pigs having a lower aluminum content than the minimum for the standard grade ordered; however, the average aluminum content of the total amount of such grade in the individual shipment will equal or exceed the minimum requirement of that grade.

Alcoa Standard Aluminum Alloy Pig Grades

Alloy	Approximate Composition	Form
2108	80/20 Al-Cu	One size only—1 piece—approximately 50 pounds
2159	88/8/4 Al-Cu-Ni	
2312	88/12 Al-Si	
2324	90/10 Al-Si	
2359	87.5/10/2.5 Al-Si-Cu	
2400	95/5 Al-Mn	
2509	90/10 Al-Ni	
2919	97.5/2.5 Al-Cr	

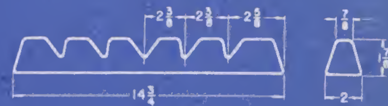
The method of making these grades (sometimes called "Rich Alloys") is such that they can only be supplied within relatively wide composition limits; hence, approximate compositions only are given above.

ALCOA ALUMINUM STANDARD INGOTS

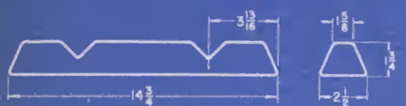
DIMENSIONS IN INCHES

Underlined figures beneath drawings indicate number of notched sections (first figure), and nominal weight in pounds (second figure).

3-2

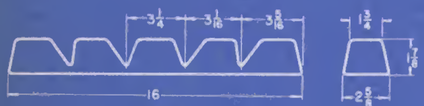


6-3



3-5

4-5



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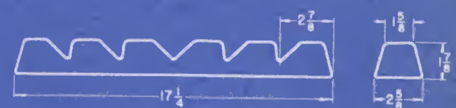

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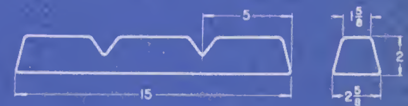
7-5



3-6

4-6

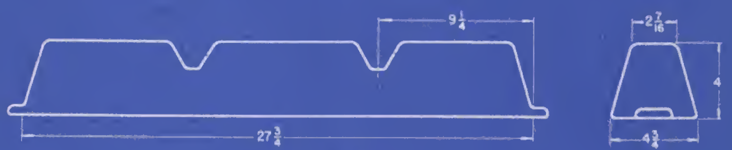
ALCOA ALUMINUM STANDARD INGOTS

DIMENSIONS IN INCHES

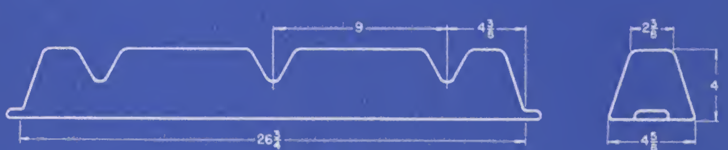
Underlined figures beneath drawings indicate number of notched sections (first figure), and nominal weight in pounds (second figure).

1-30

2-30



3-30



4-30

ALCOA ALUMINUM STANDARD PIG

1-50

TABLE III

Nominal Composition of Alcoa Aluminum and Alcoa Aluminum Alloys for Steel Additions

Alcoa Alloy No.	Form	Nominal Composition†	Remarks
99% Plus	6–3 Ingot	99.0–99.5% Aluminum	Generally used as ladle addition.
99% Plus	Granulated	99.0–99.5% Aluminum	Generally used as ladle or mold addition.
99% Plus	Grained (8 mesh and finer)	99.0–99.5% Aluminum	Thermite reaction for reducing oxides.
94% Plus Metallurgical	6–3 Ingot	94.0–97.0% Aluminum	Generally used as ladle addition.
94% Plus Metallurgical	Granulated	94.0–97.0% Aluminum	Generally used as ladle or mold addition.
97% Plus Metallurgical	6–3 Ingot	97.0% Min. Aluminum	
2806	Lump**	50% Al 50% Iron	Used for alloying.
A2806	Lump**	50% Al 50% Iron	Used for deoxidizing.
2834	Lump	20% Al 40% Iron 20% Si 20% Mn	

†Normal impurities constitute the remainder in case of aluminum. Aluminum content includes normal impurities in case of alloys.

**Lumps may reduce to a fine powder on standing for several months, so should be used promptly.

TABLE IV

Miscellaneous Physical Properties of Alcoa Casting Alloys

(Typical Values)

Alcoa Alloy No.	Density [1]		Solidification Range, °F.	Electrical [2] Conductivity, % International Annealed Cu Std. at 68° F.	Thermal [3] Conductivity, C.G.S. Units at 68° F.	Coefficient of Thermal Expansion [4] per °F. x 10^{-6}	
	Specific Gravity	Weight, Lb./cu. in.				68°–212° F.	68°–572° F.
SAND-CASTING ALLOYS							
43	2.66	0.096	1165–1070	37	0.34	12.2	13.3
45	2.65	0.096	1155–1070	31	0.29	11.5	12.5
47 [5]	2.65	0.096	1150–1070	40	0.37	11.1	11.9
108	2.75	0.099	1170–970	31	0.29	12.2	13.3
112	2.85	0.103	1175–1005	30	0.28	12.2	13.3
122	2.85	0.103	1160–1005	34	0.32	12.2	13.0
142	2.73	0.099	1165–995	36	0.33	12.5	13.6
142-T2	2.73	0.099	1165–995	44	0.40	12.5	13.6
142-T61	2.73	0.099	1165–995	37	0.35	12.5	13.6
142-T571	2.73	0.099	1165–995	..	....	12.5	13.6
172	2.83	0.102	1165–975	30	0.28	12.2	13.3
195-T4	2.77	0.100	1195–1020	35	0.33	12.7	13.8
195-T6	2.77	0.100	1195–1020	..	....	12.7	13.8
195-T62	2.77	0.100	1195–1020	37	0.34	12.7	13.8
212	2.83	0.102	1165–975	30	0.28	12.2	13.3
214	2.63	0.095	1185–1075	35	0.32	13.3	14.4
B214	2.63	0.095	1170–1090	38	0.35	13.0	14.0
220-T4	2.56	0.092	1150–840	21	0.20	13.6	14.7
A334	2.73	0.099	1160–940	31	0.29	12.2	13.3
355-T6	2.68	0.097	1160–1075	36	0.33	12.2	13.3
355-T51	2.68	0.097	1160–1075	43	0.40	12.2	13.3

TABLE IV (Continued)

Miscellaneous Physical Properties of Alcoa Casting Alloys

(Typical Values)

Alcoa Alloy No.	Density [1]		Solidification Range °F.	Electrical [2] Conductivity, % International Annealed Cu Std. at 68° F.	Thermal [3] Conductivity, C.G.S. Units at 68° F.	Coefficient of Thermal Expansion [4] per °F. x 10^{-6}	
	Specific Gravity	Weight, Lb./cu. in.				68°–212° F.	68°–572° F.
SAND-CASTING ALLOYS (Continued)							
356-T4	2.63	0.095	1130–1075	39	0.36	11.9	13.0
356-T6	2.63	0.095	1130–1075	39	0.36	11.9	13.0
356-T51	2.63	0.095	1130–1075	43	0.39	11.9	13.0
406	2.73	0.099	1255–1215	25	0.24	13.0	14.0
645	2.94	0.106	1165–980	33	0.31	13.0	14.0
PERMANENT-MOLD CASTING ALLOYS							
43	2.68	0.097	1165–1070	41	0.38	12.2	13.3
A108	2.77	0.100	....	37	0.34	11.9	12.7
B113	2.86	0.103	1175–1005	29	0.28	12.2	13.3
C113	2.86	0.103	1165–975	27	0.26	12.2	13.3
122	2.89	0.104	1160–1005	34	0.32	12.2	13.0
A132-T551	2.68	0.097	1095–1000	29	0.28	10.5	11.6
142	2.77	0.100	1165–995	34	0.32	12.5	13.6
142-T61	2.77	0.100	1165–995	..	....	12.5	13.0
142-T571	2.77	0.100	1165–995	34	0.32	12.5	13.0
B195-T4	2.78	0.101	1160–980	35	0.33	12.2	13.3
B195-T6	2.78	0.101	1160–980	50	0.45	12.2	13.3
A214	2.67	0.096	....	..	....	13.3	14.4
355-T6	2.68	0.097	1160–1075	39	0.36	12.2	13.3
355-T51	2.68	0.097	1160–1075	..	....	12.2	13.3

TABLE IV (Concluded)

Miscellaneous Physical Properties of Alcoa Casting Alloys

(Typical Values)

Alcoa Alloy No.	Density [1]		Solidification Range, °F.	Electrical [2] Conductivity, % International Annealed Cu Std. at 68° F.	Thermal [3] Conductivity, C.G.S. Units at 68° F.	Coefficient of Thermal Expansion [4] per °F. x 10^{-6}	
	Specific Gravity	Weight, Lb./cu. in.				68°–212° F.	68°–572° F.
PERMANENT-MOLD CASTING ALLOYS (Continued)							
356-T4	2.63	0.095	1130–1075	39	0.36	11.9	13.0
356-T6	2.63	0.095	1130–1075	41	0.38	11.9	13.0
DIE-CASTING ALLOYS							
13	2.66	0.096	1150–1070	36	0.33	11.1	11.9
43	2.70	0.097	1165–1070	41	0.38	12.2	13.3
81	2.85	0.103	1165–975	28	0.27	12.2	13.3
83	2.75	0.099	....	30	0.28	12.5	13.8
85	2.78	0.101	....	28	0.27	11.6	12.7
218	2.53	0.091	1160–1000	25	0.24	13.4	14.5
A254	2.66	0.096	....	18	0.18	....	....
315	2.70	0.097	1200–1070	45	0.42	....	....
505	2.80	0.101	1195–1185	33	0.31	12.4	13.4

[1] Density determinations based on samples prepared to provide maximum soundness. Density of actual castings will generally be slightly lower, particularly in the case of die castings, because of inherent internal porosity.

[2] Electrical conductivity values for sand-casting alloys determined from specimens cast in green sand molds. Values for permanent-mold and die-casting alloys determined from specimens cast in chill molds.

[3] Approximate thermal conductivity values calculated from electrical conductivity. C.G.S. units are calories per square centimeter per degree centigrade per second.

[4] Coefficient of thermal expansion values determined from specimens cast in graphite molds.

[5] Values obtained from material given special foundry practice called "modification."

TABLE V

Conforming Aluminum Casting Ingot Specifications

Alcoa Alloy No.	Federal Specification No.	U. S. Navy No.
43	QQ-A-371a Class 2	46A5 (INT) Class 2
356	QQ-A-371a Class 3	46A5 (INT) Class 3
195	QQ-A-371a Class 4	46A5 (INT) Class 4
214	QQ-A-371a Class 5	46A5 (INT) Class 5
142	QQ-A-371a Class 6	....
122	QQ-A-371a Class 7	....
108	QQ-A-371a Class 8	....
212	QQ-A-371a Class 9	....
355	QQ-A-371a Class 10	....
A355	QQ-A-371a Class 11	....
A132	QQ-A-371a Class 12	....

NOTE: Both Federal and Navy ingot specifications are used only for direct purchase of ingot by Government Agencies.

TABLE VI

Conforming Aluminum Casting Alloy Specifications[1, 2]

Alcoa Alloy No.	U. S. Navy No.	Army-Navy Aeronautical No.	Federal Specification No.	S.A.E. Aircraft Material Specification	S.A.E. No.	A.S.T.M. No.
SAND-CASTING ALLOYS						
43	46A1 (INT) Class 2	AN-QQ-A-405	QQ-A-601 Class 2	...	35	B26-41T Alloy JJ
47	...	...	...	...	37	B26-41T Alloy K
108	...	AN-QQ-A-397	QQ-A-601 Class 8	...	..	...
112	...	...	...	...	33	B26-41T Alloy C
122	...	...	QQ-A-601 Class 7	...	34	B26-41T Alloy F
142	...	AN-QQ-A-379 Class A	QQ-A-601 Class 6	4222	39	B26-41T Alloy H
172	...	...	...	...	..	...
195	46A1 (INT) Class 4	AN-QQ-A-390	QQ-A-601 Class 4	4231	38	B26-41T Alloy G
212	...	AN-QQ-A-399	QQ-A-601 Class 9	...	36	B26-41T Alloy CC
214	46A1 (INT) Class 5	AN-QQ-A-402	QQ-A-601 Class 5	...	320	B26-41T Alloy L
220	...	AN-QQ-A-392	...	4240	324	...
355	...	AN-QQ-A-376	QQ-A-601 Class 10	4210A[3]–4212A[4]–4214	322	B26-41T Alloy N
A355	...	...	QQ-A-601 Class 11	...	...	...
356	46A1 (INT) Class 3	AN-QQ-A-394	QQ-A-601 Class 3	...	323	B26-41T Alloy M
645	...	...	...	...	31	...
PERMANENT-MOLD CASTING ALLOYS						
43	46A15 Class 7	...	QQ-A-596 Class 7	...	35	B108-41T Alloy 9A
A108	46A15 Class 5	...	QQ-A-596 Class 5	...	..	B108-41T Alloy 3
C113	46A15 Class 1	...	QQ-A-596 Class 1	...	..	B108-41T Alloy 2
122	46A15 Class 2	...	QQ-A-596 Class 2	...	34	B108-41T Alloy 4
A132	46A15 Class 9	AN-QQ-A-386	QQ-A-596 Class 9	...	321	B108-41T Alloy 6

TABLE VI (Concluded)

Conforming Aluminum Casting Alloy Specifications[1, 2]

Alcoa Alloy No.	U. S. Navy No.	Army-Navy Aeronautical No.	Federal Specification No.	S.A.E. Aircraft Material Specification	S.A.E. No.	A.S.T.M. No.
PERMANENT-MOLD CASTING ALLOYS (Continued)						
142	46A15 Class 3	AN-QQ-A-379 Class B	QQ-A-596 Class 3	....	39	B108-41T Alloy 11
B195	46A15 Class 4	AN-QQ-A-383	QQ-A-596 Class 4	4282 [5]	380	B108-41T Alloy 1A
355	46A15 Class 6	AN-QQ-A-371	QQ-A-596 Class 6	4280 [6]	322	....
356	46A15 Class 8	....	QQ-A-596 Class 8	4284 [7]	323	B108-41T Alloy 10
DIE-CASTING ALLOYS						
13	46A14 Classes 1 and 2	AN-QQ-A-366, Al-13, Al-13X	QQ-A-591 Classes 1 and 2	4290A	305	B85-39T Alloy V
43	46A14 Class 3	....	QQ-A-591 Classes 3 and 8	....	304	B85-39T Alloy IV
81	46A14 Class 4	....	QQ-A-591 Class 4	....	312	B85-39T Alloy XII
83	....	....	....	....	...	B85-39T Alloy VI
85	46A14 Class 5	AN-QQ-A-366, Al-85	QQ-A-591 Class 5	....	307	B85-39T Alloy VII
218	46A14 Class 7	AN-QQ-A-366, Al-218	QQ-A-591 Class 7	....	...	....

NOTES:

[1] The above specifications are those covering the final castings. The composition of Alcoa ingot is carefully controlled to provide for any normal iron pickup during remelting and casting.

[2] Specifications issued by various government or specification agencies covering the same alloy may or may not have identical chemical composition limits. Reference to the specification in question should be made before quoting alloys listed in this tabulation.

[3] Applies to 355-T51. [4] Applies to 355-T6. [5] Applies to B195-T6.

[6] Applies to 355-T77. [7] Applies to 356-T6.

While the information on specifications is believed to be accurate as of the date of its publication, Aluminum Company of America does not accept any responsibility for any use that may be made of the data, or for errors that may occur, or for failure to advise of subsequent revisions.

TABLE VII

Mechanical Properties[1] of Alcoa Sand-Casting Alloys

Designers Note: See discussion of Mechanical Properties, page 51, before consulting this table.

Alcoa Alloy No.	Minimum Values[2]		Typical Values (Not Guaranteed)							
	Tension[3]		Tension[3]			Compression[4]	Hardness[3]	Shear[5]	Fatigue[6]	Impact[7]
	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Yield Strength (Set = 0.2%), Lb./sq. in.	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Yield Strength (Set = 0.2%), Lb./sq. in.	Brinell 10-mm. Ball 500-Kg. Load	Shearing Strength, Lb./sq. in.	Endurance Limit, Lb./sq. in.	Charpy Values, Ft.-Lb.
43	17,000	3.0	9,000	19,000	6.0	10,000	40	14,000	6,500	1.0
45	18,000	1.5	10,000	21,000	4.5	11,000	45	16,000	6,000	0.8
47[9]	24,000	5.0	11,000	26,000	8.0	11,000	50	18,000	6,000	3.0
108	19,000	1.5	14,000	21,000	2.0	14,000	55	20,000	8,500	0.6
112	19,000	[8]	14,000	23,000	1.5	17,000	70	20,000	9,000	0.6
122[10]	23,000	[8]	21,000	26,000	0.5	......	85	25,000	9,500	0.6
142[10]	23,000	[8]	24,000	28,000	1.0	......	80	24,000	8,000	0.6
142-T2	23,000	[8]	18,000	27,000	1.0	18,000	75	21,000	6,500	...
142-T61	32,000	[8]	32,000	37,000	0.5	47,000	100	32,000	8,000	0.6
142-T571[11]	29,000	[8]	28,000	32,000	0.5	34,000	85	27,000	8,000	...
172	19,000	[8]	15,000	23,000	1.0	17,000	65	20,000	.....	0.6
195-T4[11]	29,000	6.0	16,000	31,000	8.5	16,000	65	24,000	6,000	2.8
195-T6	32,000	3.0	22,000	36,000	5.0	25,000	80	30,000	6,500	1.8
195-T62	36,000	[8]	31,000	40,000	2.0	38,000	95	31,000	7,000	1.3
212	19,000	[8]	14,000	22,000	2.0	14,000	65	20,000	8,000	0.6

TABLE VII (Continued)

Mechanical Properties[1] of Alcoa Sand-Casting Alloys

Designers Note: See discussion of Mechanical Properties, page 51, before consulting this table.

Alcoa Alloy No.	Minimum Values [2]		Typical Values (Not Guaranteed)							
	Tension [3]		Tension [3]			Compression [4]	Hardness [3]	Shear [5]	Fatigue [6]	Impact [7]
	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Yield Strength (Set = 0.2%), Lb./sq. in.	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Yield Strength (Set = 0.2%), Lb./sq. in.	Brinell 10-mm. Ball 500-Kg. Load	Shearing Strength, Lb./sq. in.	Endurance Limit, Lb./sq. in.	Charpy Values, Ft.-Lb.
214	22,000	6.0	12,000	25,000	9.0	12,000	50	20,000	5,500	3.8
B214	17,000	[8]	13,000	20,000	2.0	15,000	50	17,000	.....	0.7
220-T4	42,000	12.0	25,000	45,000	14.0	26,000	75	33,000	7,000	4.2
A334	22,000	[8]	16,000	25,000	2.0	22,000	65	24,000	8,500	0.7
355-T6	32,000	2.0	25,000	35,000	3.5	29,000	80	30,000	8,500	1.0
355-T51	25,000	[8]	23,000	28,000	1.5	24,000	60	22,000	7,000	0.7
356-T4 [11]	26,000	5.0	16,000	28,000	6.0	18,000	55	22,000	.....	1.7
356-T6	30,000	3.0	22,000	32,000	4.0	22,000	70	27,000	8,000	1.0
356-T51	23,000	[8]	20,000	25,000	2.0	22,000	60	18,000	7,500	0.7
406	16,000	6.5	9,000	19,000	12.0	9,000	35	14,000	5,500	4.0
645	25,000	2.5	20,000	29,000	4.0	20,000	70	22,000	7,500	2.0

TABLE VII (Concluded)

NOTES:

[1] Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.

[2] Minimum properties of separately cast tension test specimens obtained in foundries of Aluminum Company of America, and as required by most conforming specifications. Since these results depend in a large measure on remelting and foundry practice, both beyond the control of this Company, the mechanical properties of test specimens from Alcoa ingot are not guaranteed.

[3] Tension and hardness values determined from standard half-inch diameter tensile test specimens individually cast in green sand molds and tested without machining the gauge sections.

[4] Results of tests on specimens having an l/r ratio of 12.

[5] Single-shear strength values obtained from double-shear tests.

[6] Based on specimens withstanding 500,000,000 cycles of completely reversed stress, using rotating beam type of machine and specimen.

[7] Charpy impact values as determined using 10-mm. x 10-mm. notched specimens on modified Charpy impact machine with 5.07-pound hammer.

[8] Not specified. The error in determining low elongations is comparable with the value being measured.

[9] Properties of this alloy obtained by special foundry practice, called "modification."

[10] Data listed are for alloy in as-cast condition. Many specifications require material to be heat-treated, resulting in improved mechanical properties.

[11] On standing at room temperature for several weeks the tensile and yield strengths will increase somewhat and the elongation will be reduced slightly. In the case of 195-T4 and 356-T4 alloys, the properties will approach those of the T6 condition.

TABLE VIII

Mechanical Properties[1] of Alcoa Permanent-Mold Casting Alloys

Designers Note: See discussion of Mechanical Properties, page 51, before consulting this table.

Alcoa Alloy No.	Minimum Values [2]		Typical Values (Not Guaranteed)								
	Tension [3]		Tension [3]			Compression [4]	Hardness [5]	Shear [6]	Fatigue [7]	Impact [8]
	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Yield Strength (Set = 0.2%), Lb./sq. in.	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Yield Strength (Set = 0.2%), Lb./sq. in.	Brinell 10-mm. Ball 500-Kg. Load	Shearing Strength, Lb./sq. in.	Endurance Limit, Lb./sq. in.	Charpy Values, Ft.-Lb.
43	21,000	2.5	9,000	24,000	6.0	9,000	40	18,000	.....	2.1
A108	24,000	[9]	16,000	28,000	2.0	16,000	70	25,000	.....	0.9
B113	24,000	[9]	19,000	28,000	2.0	19,000	70	23,000	.....	...
C113	25,000	[9]	24,000	30,000	1.0	24,000	80	22,000	.....	...
122 [10]	26,000	[9]	26,000	31,000	1.0	26,000	95	25,000	.....	0.9
A132-T551	31,000	[9]	28,000	36,000	0.5	30,000	105	24,000	.....	0.7
142 [10]	26,000	[9]	24,000	34,000	1.0	24,000	105	26,000	.....	...
142-T61	40,000	[9]	42,000	47,000	0.5	46,000	110	31,000	9,500	0.6
142-T571	34,000	[9]	34,000	40,000	0.0	34,000	105	26,000	10,500	0.6
B195-T4 [11]	33,000	4.5	22,000	40,000	10.0	22,000	75	30,000	9,500	...
B195-T6	35,000	2.0	33,000	45,000	5.0	33,000	90	32,000	10,000	...
A214	22,000	2.5	16,000	27,000	5.0	17,000	60	22,000	.....	...
355-T6	37,000	1.5	26,000	43,000	4.0	26,000	90	30,000	9,000	1.9
355-T51	27,000	[9]	24,000	30,000	2.0	24,000	75	......	.....	...
356-T4 [11]	28,000	5.0	18,000	32,000	9.0	18,000	60	......	.....	1.7
356-T6	33,000	3.0	24,000	40,000	5.0	24,000	90	......	.....	1.0

TABLE VIII (Concluded)

NOTES:

1 Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.

2 Minimum properties of separately cast tension test specimens obtained in foundries of Aluminum Company of America, and as required by most conforming specifications. Since these results depend in a large measure on remelting and foundry practice, both beyond the control of this Company, the mechanical properties of test specimens from Alcoa ingot are not guaranteed.

3 Tension values determined from standard half-inch diameter tensile test specimens individually cast in chill molds and tested without machining the gauge section.

4 Results of tests on specimens having an l/r ratio of 12.

5 Brinell hardness values determined from tests on commercial castings.

6 Single-shear strength values obtained from double-shear tests.

7 Based on specimens withstanding 500,000,000 cycles of completely reversed stress, using rotating beam type of machine and specimen.

8 Charpy impact values as determined using 10-mm. x 10-mm. notched specimens on modified Charpy impact machine with 5.07-pound hammer.

9 Not specified. The error in determining low elongations is comparable with the value being measured.

10 Data listed are for alloy in as-cast condition. Many specifications require material to be heat-treated, resulting in improved mechanical properties.

11 On standing at room temperature for several weeks, properties approach those of T6 condition.

TABLE IX

Typical Mechanical Properties[1] of Alcoa Die-Casting Alloys

Designers Note: See discussion of Mechanical Properties, page 51, before consulting this table.

Alcoa Alloy No.	Tension [2]			Fatigue [3]	Impact [4]
	Yield Strength (Set = 0.2%), Lb./sq. in.	Ultimate Strength, Lb./sq. in.	Elongation, % in 2 in.	Endurance Limit, Lb./sq. in.	Charpy Values, Ft.-Lb.
13	18,000	33,000	1.8	15,000	2.0
43	13,000	29,000	3.5	......	4.5
81	24,000	32,000	1.3	16,000	3.0
83	14,000	30,000	3.5	14,500	5.0
85	19,000	35,000	2.7	17,000	2.5
218	23,000	38,000	5.0	18,000	10.0
A254	......	......	......	......	......
315	......	......	......	......	......
505	......	......	......	......	......

NOTES:

[1] Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.

[2] Tension values determined from standard one-quarter-inch diameter specimens separately cast in die.

[3] Based on specimens withstanding 500,000,000 cycles of completely reversed stress, using rotating beam type of machine and specimens separately cast in die.

[4] Charpy impact values as determined using one-quarter-inch square specimens without notches.

TABLE X

Relative Weights of Equal Volumes of Various Metals

Metal	Relative Weight
Magnesium	0.644
Aluminum, Commercially Pure	1.000
Zinc	2.65
Cast Iron (Gray)	2.65
Tin	2.71
Cast Steel	2.90
Cast Brass (60% Cu-40% Zn)	3.09
Cast Bronze (90% Cu-10% Sn)	3.26
Nickel	3.30
Copper	3.31
Lead	4.20

TABLE XI

Typical Pattern Shrinkage Allowances for Sand Castings of Various Metals

Metal	Contraction Inches per Foot*
Aluminum Alloys	
Small castings of simple design	5/32
Larger castings or those of intricate design	1/8 to 1/12
Magnesium Alloys	5/32
Brass	3/16
Bronze	3/16
Gray Iron	1/10
Steel	1/4
Malleable Iron	1/8

*Shrinkage allowances for castings will vary according to the type of construction, casting dimensions and other factors peculiar to the particular material involved. If maintenance of very exact dimensions is required, the foundry which is to produce the castings should be consulted for shrinkage allowance recommendations before the pattern is made.

ALUMINUM COMPANY OF AMERICA

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DAVENPORT, IOWA	918 Kahl Bldg.
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